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EFFECTS OF LESIONS IN THE RED NUCLEI IN CATS

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The function of any part of the brain may be investigated experimentally by observing the effects of a stimulus applied to it directly, by noting the impairment of function caused by its destruction or by comparison of the reactions of an animal from which all the brain rostral to the part under investigation has been removed, with the reactions obtained when that portion has also been removed. The latter method has been used extensively in studying the rôle played by the red nucleus and subthalamus in the complex reaction patterns involved in standing and walking. The literature related to such investigations has been reviewed by Hinsey, Ranson and McNattin.[1] These authors found that a cat, from which all of the brain in front of a plane transecting the brain stem just rostral to the superior colliculi and mammillary bodies had been removed, could stand and walk. If such an animal was placed on its side, it could bring itself to an upright position and get to its feet. The movements involved in such a turning of the head, neck and body as to bring the ventral side down have been described and analyzed by Magnus[2] under the term righting reactions. To use his term, as we shall find it convenient to do throughout this article, such an animal can right itself. This is brought about in the normal animal, according to Magnus, by five reflexes: (1) optic, (2) labyrinthine, (3) body reflexes acting on the body, (4) body reflexes acting on the head and (5) cervical righting reflexes. In a cat from which all the brain above the caudal part of the hypothalamus has been removed, all of these reflexes except the first remain intact. It is believed by Rademaker[3] that the second and third reflexes have their center in the red nucleus, that the center

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1. Hinsey, J. C.; Ranson, S. W., and McNattin, R. F.: The Rôle of the Hypothalamus and Mesencephalon in Locomotion, Arch. Neurol. & Psychiat. **23**:1 (Jan.) 1930.

2. Magnus, R.: Körperstellung, Berlin, Julius Springer, 1924.

3. Rademaker, G. G. J.: Die Bedeutung der roten Kerne und des übrigen Mittelhirns für Muskeltonus, Körperstellung, und Labyrinthreflexe, Berlin, Julius Springer, 1926.

for the fourth, while not in the red nucleus, is located in the upper part of the mesencephalon, and that that of the fifth is caudal to the rostral border of the pons.

When crouching or walking the hypothalamic cat maintains a fairly normal distribution of tonus, but when the animal is supported with the limbs hanging free, there is a definite exaggeration of the tone of the extensors. This is what might be expected, since it is known that certain parts of the cerebral cortex exert an inhibitory influence on tonus. The literature dealing with this cortical inhibition has been summarized by Ranson, Muir and Zeiss.[4] One of us (Dr. Ranson [5]) has shown that an isolated lesion of the pyramid in the cat causes a certain amount of extensor rigidity of the limbs on the side opposite the lesion.

The moderate extensor hypertonicity exhibited by a hypothalamic cat is sufficiently under control so that the animal can crouch in a normal manner, and in this way differs from the decerebrate rigidity that results when the brain stem is transected caudal to the mammillary body. However, such a transection as the latter in the rabbit does not cause decerebrate rigidity, but produces a preparation the behavior of which resembles that of a hypothalamic cat. For this reason Hinsey, Ranson and McNattin were unable to decide whether the region immediately above this level contained an important tone-inhibiting center in the cat or whether in this animal such a section produced its effect by impairing the function of the subjacent red nucleus and the tegmentum surrounding it. It was found, however, that when the transection was made caudal to the red nucleus the rigidity was even more marked (Ranson and Hinsey [6]), showing that either the red nucleus or the reticular formation within which it lies exerts an important inhibitory influence on extensor tonus. There is reason to believe, as shown by Bremer [7] and a number of earlier investigators, that through this nucleus the anterior lobe of the cerebellum may bring inhibitory impulses to bear on rigidity of the decerebrate type. Such effects, according to these workers, are abolished by section just caudal to the red nucleus. However, Bernis and Spiegel [8] have more recently shown that stimulation of

4. Ranson, S. W.; Muir, J. C., and Zeiss, F. R.: Extensor Tonus After Spinal Cord Lesions in the Cat, J. Comp. Neurol. **54**:13, 1932.

5. Ranson, S. W.: Rigidity Caused by Pyramidal Lesions in the Cat, J. Comp. Neurol., to be published.

6. Ranson, S. W., and Hinsey, J. C.: Extensor Tonus After Transection of the Brain Stem at Varying Levels, J. Nerv. & Ment. Dis. **70**:584, 1929.

7. Bremer, F.: La fonction inhibitrice du paléo-cérébellum, Arch. internat. de physiol. **19**:189, 1922.

8. Bernis, W. J., and Spiegel, E. A.: Die Zentren der statischen Innervation und ihre Beeinflussung durch Klein- und Grosshirn, Arb. a. d. neurol. Inst. a. d. Wien. Univ. **27**:197, 1925.

the lateral part of the anterior lobe of the cerebellum, even in decerebrate cats of the Sherrington type, causes not only inhibition of extensor hypertonus, but actual flexion of the fore limbs as well; the pathway postulated here would pass from the fastigial nucleus to the reticular formation of the medulla by way of the restiform body. Rademaker[9] expressed the belief that the results reported by the different workers are sufficiently contradictory to leave one in doubt as to the exact action under normal circumstances of impulses from the cerebellum which pass to the spinal cord via the red nuclei, but suggested that the rigidity that frequently follows decerebellation may be due to suppression of the red nucleus as the result of shock or diaschisis rather than to the removal of an inhibitory influence resident in the cerebellum.

While it may be regarded as definitely established that the rostral part of the mesencephalic tegmentum contains a mechanism capable of inhibiting extensor tonus, it has not been demonstrated satisfactorily that the center for this inhibition is located in the red nucleus. Rademaker[3] presented evidence in favor of such a localization. In normal as well as in thalamic rabbits he severed the rubrospinal tracts in the tegmental decussation and found that this caused extensor rigidity, which was more marked in the thalamic animals than in those in which the corticospinal tracts were intact. If it were entirely clear that the damage to the rubrospinal tracts was what produced these results, the responsibility would be fixed on the red nucleus, but Spitzer[10] and Lorente de Nó[11] have suggested that section of the decussation of Forel as performed by Rademaker will also sever a commissural path between the vestibular nuclei. These nuclei, they believed, contain tonus-inhibiting centers side by side with those responsible for decerebrate rigidity, and section of this commissural path removes the inhibitory influence responsible for the maintenance of normal tonus. For an evaluation of Rademaker's results it is important to bear in mind the fact that medial sagittal section of the pons also causes hypertonus. Section from the dorsal side, cutting the crossed vestibulospinal tract (Gray[12] and Lorente de Nó[11]), and section from the ventral side, cutting the pontocerebellar fibers (Langworthy[13]),

9. Rademaker, G. G. J.: Das Stehen, Berlin, Julius Springer, 1931.

10. Spitzer, A.: Anatomie und Physiologie der zentralen Bahnen des Vestibularis, Arb. a. d. Neurol. Inst. a. d. Wien. Univ. **25**:422, 1924.

11. Lorente de Nó, R.: Labyrinthreflexe auf die Augenmuskeln nach einseitiger Labyrinthextirpation, Berlin, Urban & Schwarzenberg, 1928.

12. Gray, L. P.: Some Experimental Evidence on the Connections of the Vestibular Mechanism in the Cat, J. Comp. Neurol. **41**:319, 1926.

13. Langworthy, O. R.: The Area Frontalis of the Cerebral Cortex of the Cat, Its Minute Structure, and Physiological Evidence of Its Control of the Postural Reflex, Bull. Johns Hopkins Hosp. **42**:20, 1928.

cause rigidity. There is need for a reinvestigation of the effects produced by median sagittal section of the brain stem to determine more definitely the nature of the decussating fibers the cutting of which releases extensor rigidity.

Ranson, Muir and Zeiss [4] found that while lesions in the dorsal part of the lateral funiculus in the first cervical segment of the cat's cord, severing the corticospinal and rubrospinal tracts, lead to an increase in extensor tonus, it was by no means clear that section of the rubrospinal tract was a factor in the result. In two animals, in which the rubrospinal tract was injured while the corticospinal fibers escaped, no rigidity developed, and in one of these there was weakness in the hind limb on the side of the lesion. Gray,[12] drawing his conclusions both from his own experiments and from those of Papez, whose records were at his disposal, stated that a lesion of the rubrospinal tract "causes weakness on the same side, dysmetria, some indifference to awkward postures, and a tendency to disuse of the affected side."

Granting that the red nucleus exerts an inhibitory influence on extensor tonus, it does not necessarily follow that this influence is mediated through the rubrospinal tract. It may be exerted through the rubroreticular and reticulospinal fibers, or through more or less direct connections of the rubroreticular fibers with the lateral vestibular nucleus. The latter is known to play an important part in the maintenance of extensor tonus. It has been found that damage to Deiters' nucleus causes hypotonus of the homolateral extensor muscles in otherwise normal animals (Fulton, Liddell and Rioch [14]), while in decerebrate animals it greatly decreased the rigidity (Spitzer,[10] Bernis and Spiegel [8] and Fulton, Liddell and Rioch [14]). Section of the direct vestibulospinal tract has a similar effect (Fulton, Liddell and Rioch [15] and Ranson, Muir and Zeiss [4]).

The first method of investigation mentioned in the opening paragraph, namely, direct stimulation, has also been used in studying the functions of the red nucleus (Ingram, Ranson and Hannett [16]). Using the Horsley-Clarke instrument, by which a bipolar needle electrode was inserted through the intact brain into the red nucleus, it has been found impossible to elicit any definite movement or alteration of posture by electrical stimulation of this structure. The faradic current

14. Fulton, J. F.; Liddell, E. G. T., and Rioch, D. McK.: The Influence of Unilateral Destruction of the Vestibular Nuclei upon Posture and the Knee-Jerk, Brain **53**:327, 1930.

15. Fulton, J. F.; Liddell, E. G. T., and Rioch, D. McK.: The Influence of Experimental Lesions of the Spinal Cord upon the Knee-Jerk: I. Acute Lesions, Brain **53**:311, 1930.

16. Ingram, W. R.; Ranson, S. W., and Hannett, F. I.: The Direct Stimulation of the Red Nucleus in Cats, J. Neurol. & Psychopath. **12**:219, 1932.

employed was of low intensity, but of sufficient strength to call forth characteristic movements and postural adjustments from most parts of the tegmentum of the mesencephalon and pons. We may therefore say that electrical stimulation of the red nucleus in animals with intact brains does not produce any noticeable reaction.

The second method, involving observation of the impairment of function caused by a sharply circumscribed lesion, has also been employed in the study of this structure. The location of the red nucleus makes it difficult to reach in the intact brain, and the lesions that Rademaker produced by lateral puncture of the midbrain were not accurately placed and were much too extensive to yield reliable information. Mussen [17] used the Horsley-Clarke instrument to place electrolytic lesions. According to this investigator, restricted lesions in the caudal poles of both red nuclei, destroying their magnocellular portions and causing complete bilateral degeneration of the rubrospinal tracts, caused only a slight transient unsteadiness of gait. On the other hand, a lesion in the anterior pole of one red nucleus resulted in loss of the righting reflexes and a transient decrease in muscle tonus. Whether the hypotonus was unilateral or bilateral is not stated, and only one experiment is recorded. The experiments reported by Mussen are few, and only meager details are given in regard to them. The method, however, is an excellent one and, if skilfully applied in a sufficient number of experiments, should lead to convincing results. The present investigation is an attempt to meet these conditions and to ascertain what effect is produced by sharply circumscribed bilateral lesions in the red nuclei.

METHODS

The Horsley-Clarke stereotaxic instrument was used in these experiments. The manner in which this apparatus may be employed for stimulation of selected areas in the interior of the brain has been described in a previous paper (Ingram, Ranson, Hannett, Zeiss and Terwilliger [18]). It may also serve to particular advantage in producing lesions, the location of the area to be destroyed being charted by the use of microscopic sections especially prepared in the manner described by Ingram, Hannett and Ranson.[19] In brief, the tip of an insulated bipolar needle electrode may be placed at any point the relation of which is known with reference to the point of intersection of three planes: a zero horizontal plane passing through the brain stem at a level one-third the distance from the external auditory meatus to the vertex, a transverse interaural plane perpendicular to the

17. Mussen, A. T.: Experimental Investigations on the Cerebellum, Brain **50**:313, 1927.

18. Ingram, W. R.; Ranson, S. W.; Hannett, F. I.; Zeiss, F. R., and Terwilliger, E. H.: Results of Stimulation of the Tegmentum with the Horsley-Clarke Stereotaxic Apparatus, Arch. Neurol. & Psychiat., this issue, p. 513.

19. Ingram, W. R.; Hannett, F. I., and Ranson, S. W.: The Topography of the Nuclei of the Diencephalon in the Cat, J. Comp. Neurol., to be published.

former and the midsagittal plane, which is, of course, perpendicular to each of the others. When the instrument has been adjusted to the head of an anesthetized cat by means of clamps on the upper jaw and pivots in the external auditory meatus, the electrode may be inserted to the proper point in the brain by use of a needle carrier controlled according to millimeter scales on the instrument.

The bipolar needle electrodes employed were similar to those previously used for stimulation. They were made of enameled nichrome wires, perfectly straight, cemented together and reinsulated with chlorinated rubber solution. Such needles, when constructed of 22 and 28 gage wires, are less than 1 mm. in thickness and possess sufficient rigidity to permit direct penetration of the dura. The latter operation is facilitated by grinding the tip to a suitable point, and in this procedure the bare ends of the wires may be adjusted to give a suitable separation of the poles of the electrode. It is, of course, important that these needles be straight and properly insulated. Defects in the insulation, no matter how minute, tend to cause "leaks" of current which may result in the production of several small lesions along the course of the needle rather than a single good-sized one at its tip. Passage of a direct current of low amperage through such an instrument, when the latter is properly placed in the brain, creates a rounded lesion of dimensions depending on the strength or duration of the current.

Two series of experiments are reported here. The first consisted of acute cases, in which no asepsis was attempted and in which the behavior of the animals was observed from three to four hours after the operation (a period of time that allows sufficient recovery from light ether anesthesia to make accurate observations possible), and again from five to six hours after the operation. These were thought to be of value because observations could be made before the occurrence of functional compensation for the loss of the part in question. The second group included so-called chronic cases in which the animals were kept for from fourteen to twenty-one days after operation, the operation having been performed under the most careful aseptic conditions. Use of the stereotaxic instrument with asepsis is rendered somewhat difficult by the necessity of inserting pivots into the external auditory meatus. To expose these openings properly in the cat one must incise the tragal portion of the pinna, and in spite of every precaution such wounds often become infected, furnishing the chief obstacle to good postoperative recovery. Danger from meningitis or infection of the scalp wound was found to be negligible if due care was taken. The exercise of aseptic precautions was greatly facilitated by the use of pentobarbital sodium as an anesthetic. In the acute experiments, in which rapid recovery was desired, ether was employed.

The procedure in one of the "chronic" experiments was as follows: A cat was anesthetized by intravenous injection of a solution containing 1½ grains (0.09 Gm.) of pentobarbital sodium. The hair was then removed from the top of the head and closely trimmed from around the ears. The latter were carefully cleaned with alcohol. The scalp over the vertex was sterilized with iodine and opened by a midline incision. A suitable opening was made in the parietal bones by use of a small trephine and rongeur forceps, after which the scalp wound was closed with metal clips. The external auditory meatuses were then exposed, and the stereotaxic instrument, which had been sterilized by immersion in alcohol, was adjusted to the head. After this had been accomplished the wound was reopened and the needle electrode inserted through the dura at the desired points. Bilateral destruction of the red nuclei was accomplished by placing in each of these nuclei a series of five small electrolytic lesions, 1 mm. apart, rostrocaudally. Each lesion fused with those adjacent to it to form an elongated lesion 4 mm. in extent. The tip of the needle electrode was placed in the rostral portion of the red nucleus, a

point which in terms of the coordinates of the stereotaxic instrument was 5 mm. rostral to the transverse interaural plane, 1.5 mm. lateral to the midline and 4.5 or 5 mm. below the zero horizontal plane. A 1 milliampere current of thirty seconds' duration produced a lesion of the desired size. The needle was then withdrawn and reinserted 1 mm. farther caudad and another lesion produced; this procedure was repeated until the series was complete; then the nucleus of the opposite side was attacked by the same process. By this method each red nucleus was practically completely destroyed from the level of the oculomotor nerve caudad. At the close of the operation the instrument was removed, the scalp incision was closed with metal clips, and gauze dressings were applied to the wounds in the ears. The latter were opened on the following day to permit drainage. The animal was then kept in a warm place for twenty-four hours, or until completely recovered from the effects of the anesthetic. Careful observations of the animal were made nearly every day for two weeks, or until the animal was killed, and occasionally motion pictures were taken. Rigidity of the limbs was studied by suspending the animal in a canvas hammock with the legs protruding through holes. This method has been found best for making observations in cases in which the extensor tonus was not sufficiently exaggerated to prevent walking. At the end of the fourteen day interval the animal was killed by bleeding and a diluted solution of formaldehyde, U.S.P. (1:10), or, if Marchi preparations were to be made, Müller's fluid was injected into the head. Sections of the formaldehyde-fixed brain stems, 40 microns thick, were cut serially, and every fourth section was mounted and stained by Weil's method. A portion of the cervical spinal cord was prepared by the Marchi technic, to demonstrate the extent of degeneration of the rubrospinal tracts.

OBSERVATIONS

Acute Experiments.—Ten cats are included in the series of acute experiments. In eight of these there was practically complete destruction of the rubrospinal pathway at its source by direct lesions in the red nuclei, the crossed rubrospinal tracts or the decussation of Forel, the damage extending rostrad as far as the rostral or middle fibers of the third nerve and caudad to the rostral part of the pons. In each of these there was extensive injury to the red nuclei themselves, especially to the so-called magnocellular or compact portions, the damaged areas usually extending ventrad to involve the crossed rubrospinal tracts. The most rostral or diffuse portions of the nuclei remained largely intact. A few cases showed lateral displacement of the lesions, which, while affecting the red nuclei only in part, caused such extensive destruction in the decussation of Forel as to insure the severance of nearly all the rubrospinal fibers. In two cats many red nucleus cells and rubrospinal fibers escaped intact, as the lesions did not extend as far rostrad as in the other eight, in which the area of injury reached the level of the third nerve. Cat 202, in which the rubrospinal tracts were extensively damaged, retained a large portion of each red nucleus, with the possibility of many normal rubrospinal connections. In cat 205, the red

nuclei were greatly injured but not completely eliminated, while the rubrospinal tracts were not affected by the lesions.

Of the eight cats with complete or almost complete destruction of the red nuclei caudal to the third nerve, all but one were able to walk rather well, although not perfectly, within several hours following the operation. All exhibited a more or less characteristic pattern in their gait, which was marked chiefly by poorly coordinated, awkward movements of the limbs. They walked with something of a shuffle, the hind limbs executing a sort of skating movement caused by the shoving of the feet forward and outward for a short distance after being placed on the floor. There was a tendency to overstep, the fore limbs being extended rather far forward, the hind limbs often striking the fore foot of the same side or shooting laterally. Scissoring movements of the limbs were frequently seen, especially in the fore limbs, and the hind limbs were usually so placed as to afford a wide base. Often the feet were handled poorly, the weight being placed on the dorsum of the toes of the hind feet rather than on the sole pads, or on the dorsal aspect of the wrists. Usually, the gait tended to improve slightly within a few hours, as the animal became stronger. In the early observations there was frequently considerable weakness, which obscured the picture to some extent.

All of these animals could right themselves when placed in recumbent positions, could rise and stand, the latter being, of course, a prerequisite for the walking described. It is difficult to tell which of the righting reflexes studied by Magnus and Rademaker was the controlling factor in this performance. In most of the cats the optic righting reflexes were not eliminated. Three of the animals, however, were blindfolded by placing a mask over the face, but showed no impairment of their ability to orient themselves, stand or walk. This leaves the labyrinthine reflexes, the body-righting reflexes "on the body" and the body-righting reflexes "on the head" as possible factors. According to Rademaker, the first two of these are ruled out by lesions affecting the spinal connections of the portions of the red nuclei destroyed in these cases. The body "on the head" reflex, however, according to this author, would still remain, and must have been the effective agent in these instances, provided Rademaker is correct in stating that the labyrinthine and body "on the body" reflexes really have their center in what he calls the magnocellular part of the red nucleus.

The one cat in this group that did not walk well exhibited a marked forced twisting of the head and curvature of the spine toward one side which permitted her to take but few steps in a circle to the left. In this case the lesion apparently extended quite far rostrad, perhaps involving the diffuse portion of the red nucleus. The medial longitudinal fasci-

culus on one side was affected here, and possibly the interstitial nucleus. The righting reactions were fairly good, especially from the right side.

Although the animals were able to walk and assume crouching postures, certain changes in tonus occurred which were studied by suspending the cats in a hammock, as already described. A normal animal in such a situation holds the limbs flexed and offers no resistance to passive flexion, or if it does so this resistance is variable and obviously due to voluntary contraction. If the cat has any tendency to rigidity, however, the limbs are usually wholly or partly extended, and there is an evident resistance to passive flexion. This was regularly tested in two ways: (1) by upward pressure exerted against the pads of the toes, thus eliciting the Stütz reflex, and (2) by grasping the leg above the wrist or ankle and bending the elbow or knee, in which case a pure stretch reflex is brought into play. For the sake of brevity we shall refer to the rigidity disclosed by the first method as the Stütz reflex and that by the second method merely as resistance to passive flexion. Extensor tonus in this series was also studied when the animals were lying on their sides or supine in a trough devised for the purpose.

All but one of the animals in this series of experiments manifested extension of the limbs when in the hammock. However, one of these, cat 205, showed extension of the limbs on the left side only; this cat was one of those in which the rubrospinal connections were only partially destroyed. Cat 206 also held only the fore limbs extended. One animal, cat 211, did not show extension; however, the limbs were not held flexed in this case, but rather in a neutral position. All but two could flex the limbs voluntarily. In every instance the Stütz reaction was obtainable, in varying degrees in different animals, but of fairly good consistency in the four limbs of most individuals. There was also resistance to passive flexion. The amount of resistance present in these cases was not always consistent with the extent of the Stütz reaction in the same individual. In six cats the Stütz reaction and the resistance to passive flexion were uniform for each limb. In the other four, resistance was not always proportionate to the Stütz reaction in every instance; for instance, cat 206 demonstrated a marked Stütz reaction in every limb, whereas the resistance to passive flexion was but slight. Whether these slight discrepancies depended on individual differences, normally present in the animals, or on physiologic differences in the effects of the lesions cannot be ascertained at the present time. It is of interest, however, to point out that in cat 205, in which the extent of destruction was doubtful, the Stütz reaction was most marked in the left limbs, while the resistance to passive flexion was present in the left limbs only, indicating, perhaps, rather complete severance of the rubrospinal, rubroreticular pathway from the right red nucleus.

When the animal was supine its behavior was similar to that shown when suspended, although there was not so great a tendency to extension of the limbs—in two cats no extension was evident. Resistance to passive flexion and the Stütz reaction were manifest to different degrees in each case; in seven cats the extent of these reactions was consistent for each limb. In general, the responses were not so marked as when the animals were suspended.

In five of the cats the state of tonus of the limbs was tested when the animals were at rest, lying on their sides. In each instance rigidity was evident in all the limbs (both the Stütz reaction and resistance to passive flexion). This was usually the least on the downward side.

The behavior of the two cats in which the damage to the red nuclei and rubrospinal tracts was less complete may be mentioned briefly. These animals could walk well, exhibiting a tendency to overstep with the hind limbs, and occasionally getting the toes bent under as the weight was thrown on to that particular limb. In cat 202, slight to moderate rigidity was present in all four limbs. In cat 205, the rigidity was slight on the right and stronger on the left; this condition has already been discussed.

Summary: The observations on eight cats in which the red nuclei were practically completely destroyed with the exception of the more diffuse parts situated rostral to the third nerve and on two in which the lesions were less extensive show that within a few hours such animals are capable of righting themselves and exhibiting a type of locomotion characterized by poor coordination, overstepping, slight ataxia, especially evident at times in placing the feet, and shuffling movements of the hind limbs. A more or less mild extensor rigidity is readily demonstrable when the animals are suspended in a hammock, held in a supine position or lying on the side. This rigidity is not of sufficiently high grade to interfere seriously with locomotion, since the cats are capable of assuming a crouching position when standing, or of flexing the limbs voluntarily when suspended.

Chronic Experiments.—In seven of eleven cats on which aseptic operations were successfully performed the rubrospinal and rubroreticular connections were almost or practically completely destroyed at their source. Six of the seven animals were kept for fourteen days or longer; one lived only five days. In the four other cats it was obvious that a considerable number of red nucleus cells were left intact. Microscopic preparations of the brain stems of the group of seven cats just mentioned showed the lesions to extend from the level of the rostral fibers of the third nerve to the rostral part of the pons in five cases, and in two the anterior border of the lesion approximated the fibers of the middle part of the third nerve. In every case the damage to the red nucleus and its descending pathways was very great, although the lesions

were restricted to rather close limits. Usually the survival of any cells of the compact portion of the nucleus was compensated for by extension of the lesion to involve the fibers crossing in the decussation of Forel or descending in the crossed rubrospinal tract. It is possible that a few fibers may have escaped in certain of these instances, but the number must have been very small.

The behavior of these cats was carefully studied nearly every day during the period of survival. After they had completely recovered from the operation, all displayed ability to right themselves, stand and walk. The gait was characteristic and similar to that described for the acute experiments. All showed a tendency to overstep, this being occasionally carried almost to absurd extremes, especially in the early stages. There was a certain amount of incoordination and apparent stiffness in the movements of the limbs, and few of the animals, even two weeks after the operation, showed any desire to indulge in the gymnastics that are the habit of normal cats. Often the hind limbs were circumducted, swinging in an arc to the side in being brought forward; along with this occurred the shuffling or skating movements previously described. Frequently, the toes were doubled under as the weight was thrown on the foot. In these experiments this occurred most commonly and was of most persistent duration in the hind limbs, although the same phenomenon was occasionally characteristic of the fore limbs in the days immediately following the operation. The righting reflexes elicited when the animal was placed in various positions on the floor were normal; only one of these cats was unable to walk the day after operation, evidently due to weakness, and this disability disappeared in a few days. On the last day of each experiment the optic righting reflexes were eliminated by quickly enucleating the eyes or performing a bilateral retinectomy under ether anesthesia; following recovery all the animals still gave evidence of their ability to right themselves and, in every case but one, to walk. The one exception to the last statement was a cat convalescing after a severe infection of the ears, which was too weak to recover rapidly from the second operation. As has been indicated before, no attempt was made to determine whether this righting ability depended on the existence of labyrinthine, "body on the body" or "body on the head" reflexes. In any case, the righting reactions remained normal, for all practical purposes, even after the production of extensive, yet restricted, lesions in the rubral portion of the tegmentum.

In general, aside from the characteristic features of the gait as already described, the behavior of these animals was normal. They crouched or sat in the positions peculiar to the cat, ate heartily, occasionally fought among themselves and, when freed from their cages, exhibited the usual restless exploratory tendencies.

The amount of rigidity present in the limbs was examined by the suspension method previously discussed. Resistance to passive flexion and the Stütz reflex were both present in all the limbs of each cat in the first days of the experiment and persisted to varying extent, in certain of the limbs, at least, during the balance of the period. In general, these reactions diminished in intensity as time went on, but were usually detectable in some, if not all, of the limbs throughout the experiment. Resistance to passive flexion was the first to diminish, the Stütz reaction, always strongest, remaining the most pronounced. The resistance to passive flexion seems to be the more difficult to elicit in limbs the rigidity of which is slight and to be easily susceptible to compensations that take place in the course of the chronic experiments. There seems to be considerable inconsistency in the degree to which the Stütz reaction and resistance to passive flexion are evident in the same limb in many cases. It is difficult to determine whether or not these differences are only apparent, depending on individual differences in animals, variations in physiologic condition or the personal element introduced by the observer. Active flexion of the limb, either voluntary or reflex, excited by contact of the hand with the limb, frequently enters as a disturbing factor in studying resistance to passive flexion, but rarely occurs when the Stütz reaction is being elicited. There may be more important factors involved, of course, which may ultimately find explanation in further analysis of the tegmental areas subject to injury as in these cases, or in differentiation of separate elements in these similar, but yet unlike, reactions.

There was usually more or less marked extension of the limbs when the animals were suspended during the first few days of the experiment. This was of varying intensity, being most marked and most persistent in the fore limbs. After several days the extension was considerably diminished, but the limbs were never, at any time, held flexed as are those of a normal cat. The ability to flex the limbs voluntarily, as in struggling, while occasionally depressed at first, was usually evident to a certain extent as the experiment proceeded. One can expect, undoubtedly, considerable individual variation in this respect.

The behavior of the four cats in which the destruction of the red nuclei was patently incomplete was similar to that of the animals just described. In general, however, the characteristic features were less marked and less persistent. The peculiarities of the gait showed somewhat greater improvement in the course of time, and the slight rigidity diminished perceptibly. The reactions were generally variable, there was no evidence of the skating movements, the tendency to overstep was not especially marked, and in only one case was the animal inclined to step on the dorsum of the hind foot. There was increased, but somewhat variable, tonus of the extensor muscles in each instance, most

persistent in the fore limbs. Resistance to passive flexion disappeared quickly in two cases; in one it practically completely disappeared in the later stages; in the other, it was not evident after the sixth day. In each of these cases, especially in cats 212 and 216, the symptoms affected the right limbs more than the left, conforming with the anatomic findings that the left red nucleus and its descending pathway were more completely involved by the lesions than were the right.

Summary: The series of cases in which the red nuclei were largely destroyed and the animals kept for two weeks showed symptoms similar to those observed in the acute experiments. The animals were able to right themselves, stand and walk. A slightly incoordinate gait was characteristic, marked by overstepping, skating, circumductory movements of the hind limbs, noticeable stiffness and a tendency to abnormal position of the feet. There was obviously increased tonus of the extensors under suitable conditions, although the cats were able to assume natural positions when standing or at rest.

THE LESIONS

The pathology of electrolytic lesions of the type produced in these experiments, as well as the physical chemistry of their production, has been discussed by Horsley and Clarke.[20] In general, such lesions consist of a small cavity, which may become filled with a homogeneous fluid, surrounded by a sort of shell of necrotic tissue, which in turn is bordered externally by an area of edema. These areas, in the course of time, tend to become filled with phagocytic cells and glia elements, and in Marchi preparations the region around the lesion may be seen to contain great numbers of gitter cells. The size of the cavity varies somewhat. In animals killed within a few hours after the production of the lesion it is quite large (figs. 1 and 2). On the other hand, fourteen days after its production, the cavity is usually small, while in three weeks it may be entirely obliterated. Frequently it contains a small amount of blood, which has apparently entered along the needle track, and occasionally a local hemorrhage may be caused by the lesion; in the latter case, the blood usually spreads more or less diffusely into the surrounding tissue. In such instances the lesion becomes too extensive for accurate localization and the animals must be discarded. It is of some interest that in the only cases of pronounced rigidity of the decerebrate type that we have seen following operations performed as described in this paper, there have been large areas of hemorrhage through the tegmentum. Two weeks after the electrolysis the cavity is considerably diminished in size and in three weeks it has disappeared, while the region occupied by it and the surrounding necrotic zone are filled with scar tissue that remains colorless in Weil preparations, being entirely devoid of myelinated nerve fibers; sections stained with cresyl violet show intense glial proliferation in these areas. The disintegration of the necrotic zone and its invasion are under way by the fifth day. Cresyl violet preparations show that there is somewhat more extensive damage than Weil preparations indicate, as ganglion cells nearby but outside the scar may be swollen, disintegrated or undergoing neuronophagia.

The size of the lesion depends largely on the amount of current used; its shape depends to some extent on the form of the electrode, but also on the amount and

20. Horsley, V., and Clarke, R. H.: The Structure and Functions of the Cerebellum Examined by a New Method, Brain **31**:45, 1908.

confinement of the gas that is formed. Usually, it may be round, oval or flame-shaped. These points are illustrated in the figures, which do not, however, show how such lesions, 1 mm. apart in a row, fuse together to form a single elongated lesion.

Accurate localization of the area to be destroyed depends mainly on the accuracy with which the stereotaxic instrument is centered on the head. This is not always easy of accomplishment, since proper alinement on the midsagittal plane rests on the placement of pivots within cuplike plugs which must be inserted in the external auditory meatus. Since the diameter or shape of the meatus of one side may differ slightly from that of the other, one cannot always place these pivots at the same depth. This, of course, will cause the instrument to be displaced laterally, and when the needle is inserted on each side of the midline the lesions may be situated asymmetrically with reference to the latter. An obviously great deviation may be noted by the relation of the midplane of the instrument to the sagittal suture or the superior sagittal sinus externally, and may be partially corrected. However, external indications may be deceptive, as one can readily see, owing to variations in the visible contours. Such displacements are usually of slight extent, in most instances not more than a millimeter. In experiments with the red nucleus this was not without some advantages, since if the instrument was slightly off center one lesion usually severed the decussation of Forel, compensating for any cells of the nucleus that might have escaped the current. We have found the lesions to be placed symmetrically with reference to the midline in ten of twenty-one experiments (for an example see fig. 6, cat 220). In eleven instances they were somewhat displaced, usually to the right, but nearly all of them affected the red nuclei. In one of the latter the deviation was so slight that it might well be considered symmetrical. The decussation of Forel was largely or completely severed in six of the experiments in which displacement was evident; in all of them the red nuclei were greatly damaged. Such a case is illustrated by cat 207 (fig. 4). It must be remembered that cells apparently left intact by the lesion may often show severe damage when closely examined.

Localization dorsoventrad offered less difficulty, since the zero horizontal plane was always placed at a proportionate distance above the meatus. Occasionally there were displacements in this respect, but in any case the lesions were purposely located far enough ventrad so that the rubrospinal tracts and ventral portions of the red nuclei would be involved. In sixteen experiments these tracts were affected, wholly or in part. Examples are cats 204 (fig. 1), 210 (fig. 2) and 217 (fig. 3).

The rostrocaudal extent of the lesions has been previously mentioned. In over half the number of cats in the series the damage extended from the rostralmost fibers of the third nerve to the pons, and in half the remainder from the middle oculomotor fibers to the pons. In only one case, however, was it positive that the rostral diffuse portion of the red nucleus had been destroyed, and in this many cells of the compact part escaped (cat 213, fig. 5). The postoperative behavior of this animal has been summarized in the protocols following this section.

The accompanying figures illustrate a number of types of lesions, taken at one, five and fourteen day intervals after operation, and show how the red nucleus and its descending pathways may be affected by the method used in these experiments. Figure 1 (cat 204) shows lesions of the piriform type in the brain stem of a cat that was killed six hours after the operation. Owing to the slant of the section, one of these is not cut through its greatest diameter and hence appears smaller than the other. The cavity is well marked, the area of coagulation or

necrosis is compact, and the zone of softening and edema is readily perceptible. These lesions are almost symmetrical and at this level involve the middle fibers of the third nerve. The red nucleus on the right is completely destroyed, while on the left a few of the most lateral cells remain. In each instance the decussated fibers of the tegmental decussation are destroyed and the regions of the rubrospinal tracts obliterated. Figure 2 (cat 210) is taken at a point where lesions of a similar nature are fused together rostrocaudally. These show features similar pathologically to those of cat 204. In this case the caudal poles of the red nuclei are destroyed and the rubrospinal tracts are greatly involved; fibers of the most rostral portion of the decussation of the brachium conjunctivum are also affected Figure 3 (cat 217) shows an irregular and a flame-shaped lesion interrupting the

Fig. 1.—Transverse section through the brain stem of cat 204, showing lesions. Weil stain. Cat killed six hours after operation.

rubrospinal tracts. Here the red nuclei are hardly attacked, but the lesions are placed so as to destroy their spinal connections. This animal died five days after operation. Disintegration of the necrotic zone and beginning of gitter cell and glial proliferation are already evident at this time. Ganglion cells about the lesion show severe injury. There is a small amount of blood in each cavity. The lesions in these three cats were deeply situated, but although in such cases a portion of the red nucleus may escape the effects of electrolysis, the descending pathways may be destroyed. It must be remembered, of course, that each of these lesions was fused with its immediate neighbors and that similar damage was done above and below the levels represented by the sections.

In figure 4 (cat 207) is found an example of lateral displacement of the lesions. Here the puncture to the left approximates the midline and completely severs the decussation of Forel, although the red nuclei are but slightly affected. The lesion

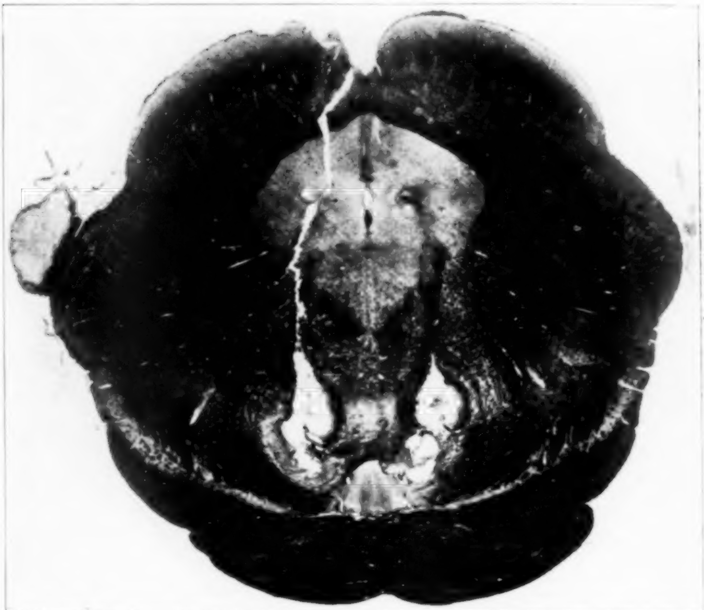

Fig. 2.—Transverse section through the brain stem of cat 210, showing lesions. Weil stain. Cat killed six hours after operation.

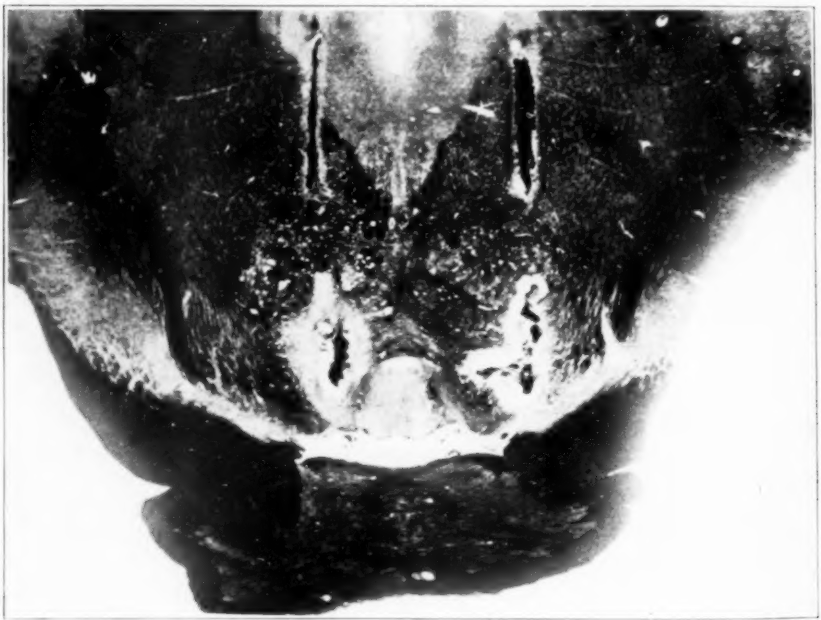

Fig. 3.—Transverse section through the brain stem of cat 217, showing lesions. Weil stain. Cat dead five days after operation.

on the right invades the substantia nigra and occupies the area through which the rubrospinal fibers pass a short distance farther caudad. A few fibers of the most rostral portion of the decussation of the brachium conjunctivum, as well as the dorsal part of the interpeduncular nucleus, are also involved by the lesion on the left. The lesions themselves possess large pear-shaped cavities, narrow necrotic areas and peripheral edematous zones. There is practically no blood in either cavity. This cat was killed six hours after the operation.

Figure 5 (cat 213) shows rounded lesions in the rostral poles of the red nuclei in a cat that was killed fourteen days after operation. At this stage the cavity is considerably diminished in size and is surrounded by an unstained area containing many gitter cells and glia elements. A distinct edematous zone is no longer

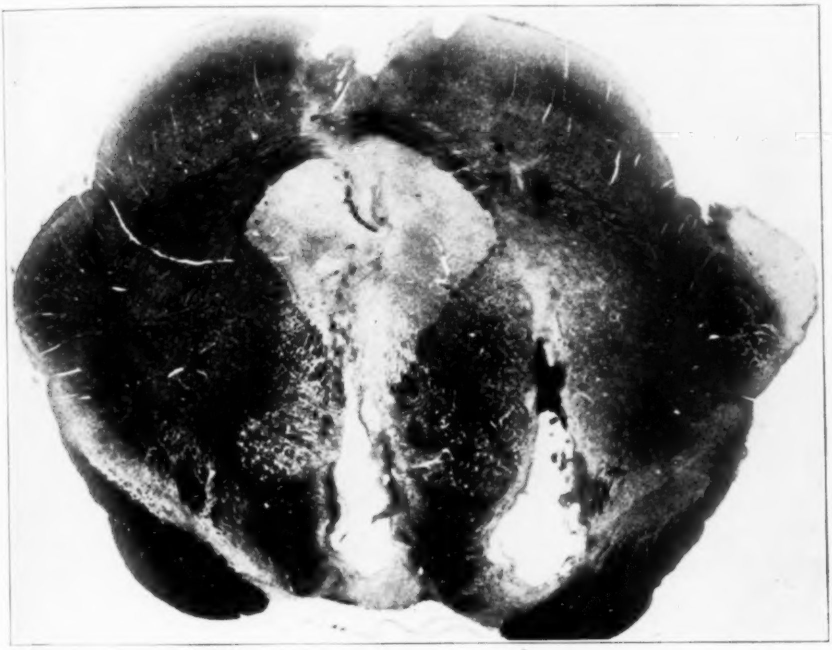

Fig. 4.—Transverse section through the brain stem of cat 207, showing lesions. Weil stain. Cat killed six hours after operation.

evident, but here again many ganglion cells are damaged. The involvement of the rostral portions of the red nuclei was practically complete in this experiment; the behavior of the animal is summarized in protocol 5.

In cat 220, the compact portions of the red nuclei were destroyed by symmetrical, well fused lesions. These are illustrated in figure 6 and show small cavities containing minute amounts of blood, and well organized areas of demyelination, filled with gitter cells, other glia elements and fibroblasts, as one would expect in two week old lesions. While the damage inflicted by this type of lesion is severe, it must be noted that its extent is restricted, with but little encroachment on structures aside from those in question. Injury done by the passage of the needle without electrolysis has been found to be limited in extent, although there is some glial reaction, and usually without physiologic significance, unless the medial longi-

Fig. 5.—Transverse section through the brain stem of cat *213*, showing lesions. Weil stain. Cat killed fourteen days after operation.

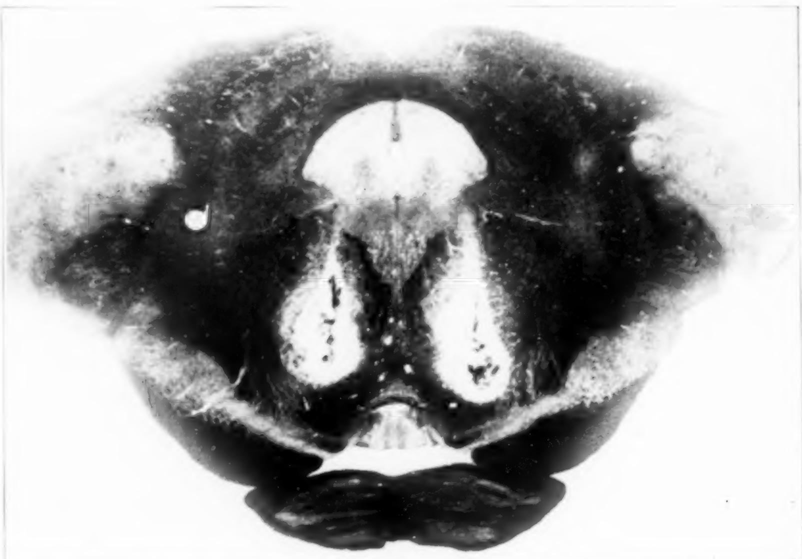

Fig. 6.—Transverse section through the brain stem of cat *220*, showing lesions. Weil stain. Cat killed fourteen days after operation.

tudinal fasciculus is severed. In this case, again, the lesions extend ventrad to affect partially the rubrospinal tracts, especially on the right side. For an account of the behavior of this cat refer to protocol 3.

Figure 7 is taken from a Marchi preparation of the brain stem of cat 226, and is included chiefly to show the degenerating fibers in the decussation of Forel. The lesion on the right side contains an unusual amount of blood, while that on the left shows a well organized core. Each contains an extensive area in which are great numbers of gitter cells, the presence of which marks the extent of the injury. While these lesions are not quite symmetrical with reference to the midline, the damage done seems to have been quite proportionate, judging by the number of degenerated fibers entering the decussation from each side. There are,

Fig. 7.—Transverse section through the brain stem of cat 226, showing lesions. Marchi stain. Cat killed fourteen days after operation.

of course, a number of degenerated tectospinal fibers in the dorsal part of the decussation. The extent to which the rubrospinal tracts were injured in this animal may be seen in figure 8, which is a section taken from the upper cervical spinal cord.

While the extent of the injury as expressed by cavitation, necrosis, etc., is readily determined by examination of the sections, one cannot thus ascertain the extent of what have been called the physiologic lesions. In comparing acute and chronic experiments, even granting the compensation that necessarily takes place, the indications are that this invisible damage to structures for a short distance around each lesion may play a small part in producing the symptoms that are evident immediately after operation. One may then consider that in cases in which the destruction of the red nuclei is apparently incomplete, the surviving cells

may be incapacitated for a certain period of time, which, probably, accounts for the similarity of symptoms in the early stages of such experiments to cases in which the injury was more extensive. The recovery that takes place to some extent in the course of chronic experiments may be in part accounted for by restorative changes in the tissues about the lesions. As has been pointed out, however, cells that in Weil preparations appear normal, in cresyl violet sections may show swelling, neuronophagia and other changes. Many cells in the red nuclei, but which are outside the lesion proper, may thus be irreparably damaged by slight spread of the electrolytic current.

That the effects produced by such lesions as have been described here must be rather specifically related to the position and extent of these lesions is borne out by observations made in many other experiments. In the course of previous work (Ingram, Ranson, Hannett, Zeiss and Terwilliger [18]), varying numbers of

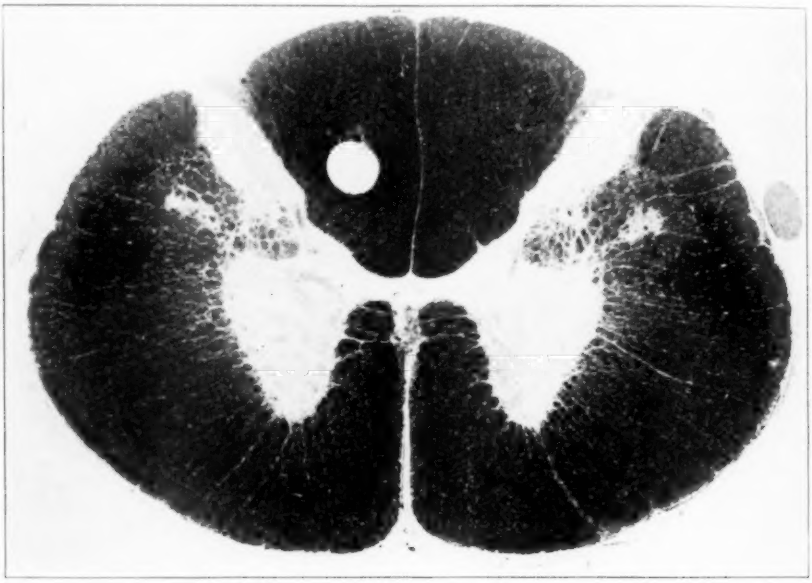

Fig. 8.—Transverse section through the cervical spinal cord of cat 226, showing degeneration in rubrospinal and tectospinal tracts. Marchi stain. Cat killed fourteen days after operation.

points in the mesencephalic tegmentum lateral to the red nucleus were stimulated in a large series of cats. In certain of these, lesions were placed to mark the spot from which a particular response was obtained. Observation over twenty-four hours in such cases disclosed no significant effects on the animal's behavior and, in nearly every instance, no increase in extensor tonus. The red nuclei were not involved here. One cat, in which such a lesion was produced under aseptic conditions, was kept for fourteen days without displaying abnormality of posture or locomotion. In another, bilateral lesions were made at some distance dorsal to the red nuceli, in the tectal regions, and following this procedure behaved in every respect like a normal animal. One receives the impression from these experiments, also, that the physiologic injury done by simple needle punctures, without electrolysis, is very slight.

CONDENSED PROTOCOLS OF CERTAIN CHRONIC EXPERIMENTS

PROTOCOL 1 (cat 214).—The animal was operated on on Oct. 2, 1931, and was killed on October 16.

Four electrolytic lesions were made aseptically in each red nucleus at points having the following coordinates: [21]

A 5, R 1.5, H 5	A 5, L 1.5, H 5
A 4, R 1.5, H 5	A 4, L 1.5, H 5
A 3, R 1.5, H 5	A 3, L 1.5, H 5
A 2, R 1.5, H 5	A 2, L 1.5, H 5

On the first day after operation the animal could right itself, could stand and could walk fairly well, but with poor coordination and apparent stiffness, overstepping to some extent and getting the toes of the hind feet turned under as the weight was placed on them. When suspended in the hammock, there was a Stütz reflex in all the limbs of such high grade that the animal could not lift the foot away from the supporting hand even when it was stimulated to struggle by pinching the tail. There was considerable resistance to passive flexion in the fore limbs, but little in the hind limbs. By the fourth day it could walk well, but dragged the toes of the hind feet. The limbs appeared to be somewhat stiff, as if it could not bend them readily, especially the hind limbs. At this time there was a good Stütz reaction in the fore limbs, but little if any in the hind limbs, while the resistance to passive flexion was negligible. This condition persisted for several days, the reactions of the limbs remaining the same, the gait showing many of the same characteristics: overstepping and stiffness of the fore limbs and marked stiffness of the hind limbs. The latter was so evident as to cause the limbs to be swung lateralward as they were brought forward, scraping the toes on the ground. On the twelfth day the gait was more striking than ever, the stiffness and overstepping being especially marked. Compared with normal cats there seemed to be increased extensor tonus evident at the shoulders, elbows and knees, and much less suppleness. The condition remained much the same until October 16. At this time the Stütz reflex persisted in the fore limbs, but no resistance to passive flexion was present. On this date the eyes were bilaterally enucleated, and on recovery from the anesthetic the cat could right itself perfectly, stand and walk. The cat was then killed. In this case differences in behavior on the two sides of the animal could not be determined.

Examination of Weil-stained preparations of the brain stem showed lesions, which involved the red nuclei, extending from the level of the rostral fibers of the third nerve to the rostral part of the pons. The most rostral, diffuse portions of the red nuclei remained partially intact. From the rostral limit caudally the lesions on the left totally destroyed the tegmental decussation and the medial half of the left red nucleus. The lesions on the right affected the lateral half of the right red nucleus and extended ventrally to involve part of the crossed rubrospinal tract. The lesions on each side were confluent rostrocaudally and extended posteriorly into the decussation of the brachium conjunctivum. Perhaps a few fibers

21. In expressing the coordinates of the stereotaxic instrument, the following symbols are used: A indicates the number of millimeters rostral to the transverse interaural plane; R, the number of millimeters to the right of the midsagittal plane; L, the number of millimeters to the left of the midsagittal plane, and H, the number of millimeters ventral to the zero horizontal plane.

from the right red nucleus escaped the lesions and crossed intact in the most caudal portion of the tegmental decussation.

Marchi preparations of the cervical spinal cord showed heavy degeneration in both rubrospinal tracts, perhaps slightly more dense on one side than on the other.

Protocol 2 (cat 217).—This cat was operated on on October 13. It was found dead on October 18.

Five electrolytic lesions were made aseptically through each red nucleus at points having the following coordinates:

A 5, R 1.5, H 4.5	A 5, L 1.5, H 4.5
A 4, R 1.5, H 4.5	A 4, L 1.5, H 4.5
A 3, R 1.5, H 4.5	A 3, L 1.5, H 4.5
A 2, R 1.5, H 4.5	A 2, L 1.5, H 4.5
A 1, R 1.5, H 4.5	A 1, L 1.5, H 4.5

On the first day the animal was weak and unable to walk, although it could right itself. When suspended, the fore limbs were rigidly extended; there were a regular Stütz reaction in all the limbs and resistance to passive flexion of fairly high grade. The next day these reactions persisted, and the cat was able to walk slowly and stiffly, extending the limbs well forward at each step. There were a tendency to step on the dorsum of the hind foot and occasionally on that of the fore foot, and a general appearance of stiffness of the joints, especially in the hind limbs. The behavior remained much the same for several days. On the third day, the Stütz reaction, while present in all the limbs, was most pronounced on the left. On the fourth day, the animal was evidently weaker, as shown by its posture in standing, the hind limbs being flexed at the knee, probably passively. The fore limbs remained straight and stiff, and in walking were placed well forward. The Stütz reaction persisted, but resistance to passive flexion was diminished. The next day the cat was found dead.

Weil preparations of the brain stem of this animal showed that while the needle had penetrated the red nuclei the lesions were somewhat more ventral than usual, involving the decussating fibers on either side, the one on the right also affecting the mammillary peduncle and a small part of the medial tip of the substantia nigra (fig. 3). The lesions affected an area extending from the middle fibers of the third nerve to the pons, and in the rostral levels the red nuclei were seriously affected. In the more caudal regions there were many cells left intact in the red nuclei; however, the decussating fibers and the rubrospinal tracts must have been practically completely destroyed. Owing to a small break in the confluence of the lesions, a few fibers from the left red nucleus might have escaped, although it is difficult to see how this could have occurred to any extent when one considers the situation of the lesions on the left side. Caudally, the rostral part of the decussation of the brachium conjunctivum was invaded, as were the regions through which the crossed rubrospinal tracts pass. The lateral tip of the left medial longitudinal fasciculus was slightly affected, and the summits of the superior colliculi were damaged where the needle entered.

Although this cat lived only five days, the usual symptoms were rather well pronounced. According to the histologic examination, a few fibers from the left red nucleus may have escaped. It is interesting in this connection to note that the Stütz reaction was in this case more pronounced on the left.

Protocol 3 (cat 220).—This animal was operated on on October 20. It was killed on November 3.

Five electrolytic lesions were made aseptically in each red nucleus, at points having the following coordinates:

A 5, R 1.5, H 4.5	A 5, L 1.5, H 4.5
A 4, R 1.5, H 4.5	A 4, L 1.5, H 4.5
A 3, R 1.5, H 4.5	A 3, L 1.5, H 4.5
A 2, R 1.5, H 4.5	A 2, L 1.5, H 4.5
A 1, R 1.5, H 4.5	A 1, L 1.5, H 4.5

On the first day following the operation, the cat was able to right itself and walk, extending the fore limbs far forward and overstepping markedly with the hind limbs, sometimes interfering with the fore limbs as it did so. The toes of all the limbs were occasionally curled under as it walked; this was especially noticeable in the hind limbs, and may have been due to failure to extend the toes as the feet were placed on the floor. The movements were rather poorly coordinated, and the animal easily lost its balance, especially when shaking the head in response to irritation from the wounds of the ears. All the limbs were held extended when the animal was suspended in the hammock; the toes of the hind feet were spread, and the claws were protruded. Voluntary flexion of the limbs was carried out without apparent difficulty. There was a marked Stütz reaction in each limb, perhaps a little greater in the left than in the right. Resistance to passive flexion was elicited in all the limbs, and was greater in the fore than in the hind quarters. Two days later, the extension of the fore limbs when the cat was suspended was of somewhat greater degree, but the hind limbs were now held neutral or partly flexed. The Stütz reaction remained much the same, but seemed a bit greater on the left. Resistance to passive flexion persisted in the fore limbs, but was absent from the hind limbs. In walking the animal overstepped with the fore limbs, especially the left, throwing the paws across the midline and sometimes striking one against the other. The movements of the hind limbs were now better coordinated, but marked overstepping was still evident, with skating movements of the feet, apparently due to lowering of the latter before the forward-swinging movements of the limbs were complete, often causing curling under of the toes. The right fore limb was lifted rather high. The gait improved in the next few days, so that the toes were no longer turned under, although the main characteristics, including the skating movements of the hind limbs, persisted. The Stütz reaction remained much the same except for a diminution of its strength in the right fore limb. The extension of the fore limbs when suspended became less noticeable, and voluntary flexion was more readily carried out. This condition lasted for several days, a gradual lessening of the strength of the Stütz reaction being evident. The general condition of the animal improved so that it could run, although it showed increased awkwardness when moving rapidly. The movements, while more supple, were still somewhat stiff, and the characteristic features of the gait were retained, with persistent emphasis on extensor movements. The day before it was killed it showed extension of the fore limbs when suspended, ability to flex all the limbs voluntarily, a moderate Stütz reaction in both fore limbs and some resistance to passive flexion in the right fore limb. The reactions of the hind limbs were obscured by voluntary movements. There was little change in the gait, which, although the animal was strong and active, showed the long strides and stiffness of the hind limbs with slight skating movements. On the fourteenth day the eyes were bilaterally enucleated, and on recovery the cat demonstrated ability to right herself from either side and walk. The animal was then killed.

Weil preparations of the brain stem of this cat showed large, round lesions extending through the red nuclei (fig. 5) from the rostral fibers of the third nerve to the pons. While the main bodies of the red nuclei were apparently completely destroyed, the rostral diffuse portions remained partially intact. The lesions in this case extended ventrally far enough, especially on the right, to involve the regions of the rubrospinal tracts, although it is doubtful if these were completely destroyed in this aspect, and also caudally to destroy the brachium conjunctivum partly on each side at the level of the decussation of the latter.

Marchi preparations of the cervical spinal cord displayed heavy degeneration of the rubrospinal tracts.

The behavior of this animal was quite typical, and the microscopic material gives evidence that the symptoms presented in this case were due to practically complete destruction of the red nuclei caudal to the third nerve.

Protocol 4 (cat 223).—This cat was operated on on October 27. It was killed on November 16.

Five electrolytic lesions were made aseptically in each red nucleus, at points having the following coordinates:

A 5, R 1.5, H 4.5	A 5, L 1.5, H 4.5
A 4, R 1.5, H 4.5	A 4, L 1.5, H 4.5
A 3, R 1.5, H 4.5	A 3, L 1.5, H 4.5
A 2, R 1.5, H 4.5	A 2, L 1.5, H 4.5
A 1, R 1.5, H 4.5	A 1, L 1.5, H 4.5

On the first day following operation, the animal could right itself and was able to sit up, but tended to assume distorted positions and to stiffen out and lose its balance with sudden movements. The Stütz reaction and resistance to passive flexion were fairly good, being greater in the right limbs than in the left. The next day the cat could stand fairly well, with the head turned slightly to the left, but was unwilling to walk. When suspended in the hammock, it had difficulty in flexing the hind limbs and could not flex the fore limbs at all, all the members being held partly extended. The Stütz reaction was most prominent in the right limbs; the resistance to passive flexion was observed in the fore limbs, but was not definite in the hind limbs. The condition remained much the same for several days, the animal being somewhat weak owing to infection of the ears. On the thirteenth day it could walk and run, but with a tendency to fall toward the left, the left hind limb having a disposition to shoot out laterally or to give way. There was some overstepping, especially by the right fore limb. There was a fair Stütz reaction in the right limbs, but slight in the left. Resistance to passive flexion was slight and irregular. The next day the cat could walk straight, but only when moving slowly; when rapid movements were made, it was inclined to turn to the left. The fore limbs were slowly extended far forward, and the hind limbs were permitted to extend far to the rear before being brought forward for the next step. The Stütz and other limb reactions remained the same. There was not a great deal of change in the next few days. The slow motion effect persisted in its gait; there were great overstepping and scissoring of the limbs; the toes of the hind feet were dragged, but the tendency to lose balance diminished. The Stütz reaction was persistently greater on the right side than on the left, and became less marked as time went on. Resistance to passive flexion was variable, on the last day being present in the right limbs only. On the twentieth day the retinas were removed. Following recovery from the anesthetic the animal was able to right herself when

laid on either side on the ground, but did not rise, probably because of persisting weakness and the effects of the second operation. It was killed at this time.

Marchi preparations of the brain stem indicated that parts of the rostral, diffuse portions of the red nuclei escaped, although the lesions extended from the pons to the level of the rostral fibers of the third nerve. The needle punctures were slightly displaced to the right. The left lesion was close to the midline and destroyed the tegmental decussation throughout its extent, except at one point where a few fibers from the right red nucleus probably crossed unharmed in the ventral part of the decussation. The lesion on the right involved a great part of the right red nucleus laterally, extending ventrally into the upper portion of the crossed rubrospinal tract in its more rostral levels. In the medulla and cervical spinal cord there was heavy degeneration of both rubrospinal tracts. In this case the left medial longitudinal fasciculus was destroyed while the right remained intact.

The behavior of this animal was undoubtedly complicated somewhat by the involvement of the medial longitudinal fasciculus, to which one is inclined to ascribe the tendency to assume queer positions and the forced movements characteristic of the earlier stages of the experiment. This factor must be added to that of the survival of a number of fibers from the right red nucleus in accounting for the differences observable on the two sides of the animal.

Protocol 5 (cat 213).—This cat was operated on on October 1. It was killed on October 16.

Five electrolytic lesions were made aseptically in each red nucleus, at points having the following coordinates:

A 5, R 1.5, H 4.5	A 5, L 1.5, H 4.5
A 4, R 1.5, H 4.5	A 4, L 1.5, H 4.5
A 3, R 1.5, H 4.5	A 3, L 1.5, H 4.5
A 2, R 1.5, H 4.5	A 2, L 1.5, H 4.5
A 1, R 1.5, H 4.5	A 1, L 1.5, H 4.5

On the first day, there was a strong, uniform Stütz reaction in all the limbs, with a high grade to moderate resistance to passive flexion. The animal could right itself well. The gait was peculiar, owing partly to the after-effects of the anesthetic; the limbs, however, appeared somewhat stiff. The next day the cat circled continuously to the left; when suspended the limbs were held in pronounced extension, a marked Stütz reaction was obtainable in all the limbs, and resistance to passive flexion was moderate but variable, being most marked in the fore limbs. Voluntary flexion of the fore limbs was carried out poorly. On the fourth day, the reactions of the limbs, when the animal was suspended, were similar to those of the previous days; the Stütz reaction, however, was strongest in the left limbs. In walking there was less of a tendency to circle, the animal being able to turn to the right as well as to the left; the hind limbs were awkwardly handled, and there was a slight overstepping at times. The right fore limb overstepped markedly and sometimes shot over to the left; the head was held twisted so that the right ear was lower than the left. For some time after this the walking movements, despite some improvement in their coordination, presented a similar picture. There were a persistent tendency to overstep, especially with the right limbs, and, apparently, slight weakness of the hind limbs, which assumed a wide base; the circling movements finally ceased, and the head was held in a more symmetrical position. The Stütz reflex had become irregular and variable by the eighth day, at which time it was strongest in the right fore limb, and shortly the reactions of the limbs became

quite indefinite. By the tenth day there was better coordination in walking and jumping. On the fourteenth day, there was still overstepping by the right fore limb, and the responses of the limbs were regular only in the latter. When blindfolded, the cat could right itself perfectly from either side. On the sixteenth day, the eyes were bilaterally enucleated under ether anesthesia. Some hours later the cat could right itself, stand and walk. It was killed on the same day.

Weil-stained sections of the brain stem indicated that the rostral portions of the red nuclei were well destroyed, the lesions extending some distance rostral to the third nerve (fig. 4). In these rostral levels the lesions also involved the regions ventral to the nuclei which would be occupied by descending fibers. Farther caudad, the ventrolateral third of the left and the ventromedial third of the right red nucleus remained unaffected, and at this level many fibers must have crossed intact in the tegmental decussation, especially from the right red nucleus. At the level of the caudal poles of the red nuclei the lesion on the left involved the tegmental decussation, destroying many of these fibers. The lateral part of the left medial longitudinal fasciculus was severed, and the uncrossed vestibulomesencephalic fibers were probably involved.

Marchi preparations of the cervical spinal cord displayed heavy degeneration in both rubrospinal tracts, slightly heavier in one than in the other.

This case was complicated by injury to the ascending vestibular connections. The evidence of increased tonus and overstepping in the right limbs conforms with the histologic evidence that the spinal connections of the left red nucleus were most affected. This experiment is of particular interest, since the lesions extended farther rostrad than in the others and the diffuse portions of the red nucleus were practically completely destroyed. Except for a marked recovery, there were no significant differences in the behavior of the animal.

COMMENT

The results obtained from the experiments just described are of particular interest in comparison with those of Rademaker and of Mussen. Rademaker's main thesis is that the difference between the behavior of a thalamic animal and that of a decerebrate animal depends chiefly on the functional condition of the red nucleus, which remains intact in the former, while in the latter it is damaged or removed. Even in animals with the rest of the brain intact suppression of the function of the red nucleus causes a change from the normal to a state of increased extensor tonus, according to this author. From his observations of cats and rabbits in which the decussation of Forel was severed or in which the red nuclei were destroyed by mechanical means, he concludes that on the elimination of the red nucleus the labyrinthine and body-righting reflexes fail, thereby so affecting the postural functions that the animal so treated cannot sit upright or rise to a standing position. However, in the present instance we have presented the results of an extensive series of experiments in which, after great injury to the red nuclei and their descending connections, the animals were capable of orienting themselves properly, rising, standing and progressing. The

tonus balance was certainly shifted to the extensor side, but not to a degree sufficient to interfere to any great extent with locomotion. One might at first suppose that these differences could depend on the presence of the intact forebrain in our cases; however, Rademaker derived certain of his conclusions from animals in which the lesions affected, supposedly, only the red nuclei, and found that in these instances the only difference from his thalamic cats was the lower degree of extensor hypertonus produced.

As indicated early in this paper, Rademaker's results have been criticized by Spitzer [10] and Lorente de Nó,[11] who believed that his lesions must have been more extensive than he thought, involving commissural fibers between the vestibular nuclei. There was also opportunity for other structures in the reticular formation to be damaged by his direct lesions, which were quite extensive. Some difficulty appears in the interpretation of his autopsy material; for instance, in the case of rabbit M, for which he reported normal tonus and posture, he believed that there was no injury to the red nuclei or Forel's decussation. From his figures, however, it is difficult for us to see how the ventral portions of the red nuclei and the rubrospinal tracts could have escaped damage, especially on the left side.

In regard to Rademaker's localization of the various righting reflexes, we can at present offer little in the way of confirmation or contradiction, since no attempt was made to differentiate "body on the body" or "body on the head" reactions. However, all of our cats could rise and stand, and nearly all could walk, even when deprived of the optic righting reflexes. These activities were not carried out by Rademaker's animals, although the "body on the head" connections were supposedly extant. It might be said that since the latter must also be true in our cases, bringing the head to an upright position would call the cervical righting reflex into play, which would then bring the body to an upright position. However, one may then point to Rademaker's rabbit O, in which the rubral system was destroyed, with subsequent rigidity and loss of labyrinthine and "body on the body" reflexes, but in which the "body on the head" and cervical righting reflexes were said to persist, without causing the animal to right its body or stand. We do not wish to deny the possibility that the red nucleus may play a rôle in these reactions, but since all of this postural mechanism is so diffusely and intricately linked together, it seems to us that there is great probability that Rademaker was affecting other, more obscure, centers with his lesions.

Other interesting comparisons are furnished by the work of Mussen,[17] who found that following destruction of the posterior poles of both red nuclei, with "complete bilateral and symmetrical degenera-

tion of the rubro-spinal tracts," the only symptom was a slight unsteadiness of gait lasting two days. During the remainder of the eighteen day survival period the gait was normal and the reflexes and muscle tone were unaffected. How far we can confirm this may be judged from the results included in this report. It may well be inquired, however, whether increased tonus of the extensors might not have been found in Mussen's case if methods of observation as herein described had been used.

Mussen also placed a lesion in the anterior pole of the left red nucleus with the field of Forel anteriorly, in a cat. The nucleus magnocellularis was not disturbed and hence there was no degeneration of the rubrospinal tract. From the lesion in the nucleus parvocellularis a crossed rubrocervical tract was traced into the lower segments of the cervical spinal cord. This cat displayed loss of righting reflexes, loss of sense of position in the left forepaw and a tendency to curve the body to the right, pivoting on the hind legs. These symptoms gradually improved, until after three weeks there were only unsteadiness in balancing and occasional turning of the head to the right. In this instance there is some question as to how far rostrally Mussen considers the red nucleus to extend. It must be remembered that while von Monakow[22] considered the parvocellular part of this structure, which is the dominant portion in man, to compose only about one third of the rostrocaudal extent of the red nucleus in the cat, certain anatomists have figured an apparently greater rostral continuation. Among these are Winkler and Potter,[23] who carried it as far as the nucleus subthalamicus. Others do not consider the red nucleus to have quite so great an extent. The rostral diffuse portion (a better term than pars parvocellularis, since such a division is not distinct in the cat, according to Davenport and Ranson[24]) fades gradually into the scattered gray of the subthalamus, and in our opinion should not be considered as extending farther cephalad than the lower, curving portion of the habenulopeduncular tract. In any case, we do not know what other structures may have been affected by Mussen's lesion, but it is not beyond reason to suppose that it may have involved the nuclei or fibers associated with the upper end of the medial longitudinal fasciculus. We have just the one instance in our series in which we are sure of the destruction of the rostral portions of the red nuclei, cat 213. This has already been described, and cannot

22. von Monakow, C.: Der rote Kern der Säugetiere und des Menschen, Neurol. Zentralbl. **13**:724, 1910.

23. Winkler, C., and Potter, A.: An Anatomical Guide to Experimental Researches on the Cat's Brain, Amsterdam, Versluys, 1914.

24. Davenport, H. A., and Ranson, S. W.: The Red Nucleus and Adjacent Cell Groups, Arch. Neurol. & Psychiat. **24**:257 (Aug.) 1930.

be interpreted so as to confirm Mussen's observations. The only practicable way of accounting for this discrepancy is by differences in the extent of the lesions, unless bilateral lesions produce a different syndrome than does a single, unilateral lesion. The latter supposition seems hardly likely, especially when one recalls that Mussen found no appreciable differences between unilateral and bilateral lesions of the posterior poles of the red nuclei, so far as rigidity and the righting reflexes were concerned. It is to be hoped that further investigation will clear up these points. The anterior poles of the red nuclei and the regions immediately cephalad to them are of particular interest in connection with the work of Hinsey, Ranson and McNattin,[1] who, it will be recalled, found that the walking pattern in cats from which the cerebral hemispheres have been removed depends on the existence of the portions of the hypothalamus and subthalamus remaining after a transection through the rostral border of the superior colliculus and the rostral portion of the mammillary body. Mella [25] located centers necessary for locomotion in approximately this region. That this pattern is not seriously interfered with by lesions of the anterior portions of the red nuclei, extending as far forward as the upward curvature of the habenulopeduncular tract, is shown by our cat 213.

It may be pointed out that there are apparently some similarities in the behavior of our cats and those from which certain areas of the cortex have been removed. According to the description given by King,[26] cats with the motor and part of the frontal cortex removed exhibit certain symptoms that resemble closely those we have observed in cats in which the red nucleus has been destroyed. This is true also of King's cases with complete extirpation of the frontal area, which showed increased tonus of the extensor muscles. Similar results are reported by Olmsted and Logan [27] and by Warner and Olmsted.[28]

We do not believe that the observations reported in this communication rule out the possibility that the red nucleus plays a part in the control of posture and locomotion. That it is indeed concerned in the regulation of tonus distribution is borne out by the experiments herein described. However, we feel justified in advancing the opinion that the red nucleus is but a part of a rather widely distributed system the complexities of which cannot be completely elucidated by the elimination

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25. Mella, Hugo: The Diencephalic Centers Controlling Associated Locomotor Movements, Arch. Neurol. & Psychiat. **10**:141 (Aug.) 1923.

26. King, W. T.: Observations on the Rôle of the Cerebral Cortex in the Control of the Postural Reflex, Am. J. Physiol. **80**:311, 1927.

27. Olmsted, J. M. D., and Logan, H. P.: Lesions in the Cerebral Cortex and Extension Rigidity in Cats, Am. J. Physiol. **72**:570, 1925.

28. Warner, W. P., and Olmsted, J. M. D.: The Influence of the Cerebrum and Cerebellum on Extensor Rigidity, Brain **46**:189, 1923.

of one of its factors. On the other hand, it has been pointed out that no movements result from faradic stimulation of the red nucleus in animals with intact brains, while tonic movements and fixation of the limbs in a posture like that assumed at a certain phase of stepping can be called forth by similar stimulation of the more diffuse reticular areas of the tegmentum outside this structure (Ingram, Ranson, Hannett, Zeiss and Terwilliger [18] and Ingram, Ranson and Hannett.[16]

RESULTS OF STIMULATION OF THE TEGMENTUM WITH THE HORSLEY-CLARKE STEREOTAXIC APPARATUS

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A number of investigators have stimulated electrically the cut surface of the mesencephalon in decerebrate animals and have described in detail the reactions elicited. The literature related to such experiments has been reviewed by Hinsey, Ranson and Dixon.[1] In general, stimulation of the pyramidal fibers in the basis pedunculi has been found to cause a rapid flexion of the fore and hind limbs of the side opposite to that stimulated, followed, on cessation of the stimulus, by prompt relaxation. However, when the stimulus is applied to the tegmentum there occurs a slow flexion of the ipsolateral fore limb and extension of the contralateral fore limb, these reactions persisting for some seconds after stimulation has ceased. Associated with these movements is a curvature of the spinal column which bends the trunk so that it offers a concavity toward the stimulated side. This curvature turns the head and tail toward the side on which the stimulus has been applied and is further related to a rotation of the spine which may twist the chin away from the side stimulated, while both hind limbs are swung out toward that side. There may also be responses from the latter in the form of ipsolateral extension and contralateral flexion, flexion of both, or, as often happens, the hind limbs may take very little part in the reaction.

This tegmental reaction is, then, fundamentally different from that which can be elicited from the basis pedunculi. Its focal point, or that from which it may be obtained most easily, has been variously located.

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1. Hinsey, J. C.; Ranson, S. W., and Dixon, H. H.: Responses Elicited by Stimulation of the Mesencephalic Tegmentum in the Cat, Arch. Neurol. & Psychiat. **24**:966 (Nov.) 1930.

Thiele[2] found that it was "below and to the side of the posterior longitudinal bundle." Brown,[3] in his first communication, located it in the region of the medial longitudinal fasciculus, although in one animal he also located a ventral focus in the neighborhood of the rostral pole of the red nucleus. In his two other papers this author attributed the response to the red nucleus, but according to the diagram that he gave his "red nucleus area" is for the most part behind that nucleus in the dorsal part of the tegmentum. From this diagram one would be led to think that his focal point was actually located in the region of the central tegmental fasciculus. Evidence indicating that the response may be elicited from the region of the red nucleus also in decerebrate animals was furnished by Hinsey, Ranson and Dixon,[1] who explored the cut surface of the midbrain with both unipolar and bipolar electrodes, and having located the focal point marked it by the insertion of a bristle. In four of the six experiments, microscopic examination of the brains showed the hair to be in the red nucleus; in one experiment it was 1 mm. dorsolateral to the red nucleus, and in the other it was found in the region of the central tegmental fasciculus.

Beyond the limits of the mesencephalon the response has been obtained from the tegmentum of the pons (Brown,[3] Környey[4]), from the rostral part of the medulla (Thiele[2]) and from the subthalamus in the region of Forel's field (Környey[4]). It cannot be elicited by stimulation of the tectum (Brown,[3] Weed,[5] Környey,[4] Hinsey, Ranson and Dixon[1]), and it can be elicited from the tegmentum after the tectum has been removed (Környey[4]). It has been obtained from the right side of the mesencephalon after the following lesions: hemisection of the left side, which had severed the rubrospinal tract below the decussation of Forel (Hinsey, Ranson and Dixon[1]); median sagittal section of the mesencephalon, which cut the rubrospinal tract at the decussation of Forel (Brown,[3] Környey,[4] Hinsey, Ranson and Dixon[1]); section of the

2. Thiele, F. H.: On the Efferent Relationship of the Optic Thalamus and Deiters' Nucleus to the Spinal Cord, with Special Reference to the Cerebellar Influx Theory of Dr. Hughlings Jackson and the Genesis of the Decerebrate Rigidity of Ord and Sherrington, J. Physiol. **32**:358, 1905.

3. Brown, T. Graham: On the Postural and Non-Postural Activities of the Mid-Brain, Proc. Roy. Soc., London **87**:145, 1913; On the Occurrence of a Plastic Flexor Tone in the Monkey, J. Physiol. **49**:180, 1915; On the Effect of Artificial Stimulation of the Red Nucleus in the Anthropoid Ape, ibid. **49**:185, 1915; Note on the Physiology of the Basal Ganglia and Mid-Brain of the Anthropoid Ape, Especially in Reference to the Act of Laughter, ibid. **49**:195, 1915.

4. Környey, S.: Experimentalstudien am Nervensystem von E. A. Spiegel: X. Tonusänderungen, insbesondere der Rumpfmuskulatur bei Reizung des Mittelhirnquerschnittes, Arb. a. d. neurol. Inst. a. d. Wien. Univ. **30**:120, 1927.

5. Weed, L. H.: Observations upon Decerebrate Rigidity, J. Physiol. **48**:205, 1914.

medial longitudinal fasciculus (Környey,[4] Hinsey, Ranson and Dixon[1]); degeneration of the pyramidal tracts (Thiele,[2] Környey[4]); removal of the cerebellum (Brown,[3] Környey,[4] Hinsey, Ranson and Dixon[1]); section of the eighth nerve (Környey[4]); section of the descending vestibular tracts (Környey[4]), and bilateral section of the first three cervical roots (Hinsey, Ranson and Dixon[1]). Környey's experiments led him to believe that the response emanated from the substantia nigra and was lost when the latter was cut away. However, Hinsey, Ranson and Dixon[1] obtained typical reactions from the tegmentum after extirpation of the substantia nigra, and they concluded that it took no essential part in the response. Ashizawa and Lewy[6] obtained similar responses by stimulation of fibers passing through the region of the caudate nucleus; the use of unipolar stimulation, however, somewhat obscures the value of their results.

All of the experimental work summarized has been done with decerebrate cats and monkeys. Such experiments do not permit very accurate localization of the stimulated points, and the possibility presents itself that an animal with an intact forebrain might respond in a different manner from a decerebrate one. It was with these points in mind that it was decided to repeat the work, using methods that would tend to eliminate these objections.

METHOD

For stimulating localized areas in the interior of the intact brain it is desirable to use a method whereby the electrodes are held steadily, despite any movements elicited in response to the stimulus, and by which a series of points, definitely allocated in respect to one another, may be accurately reached. For these reasons the stereotaxic apparatus devised by Horsley and Clarke[7] was employed. The principle on which the use of this instrument is based is that of so-called rectilinear cranio-encephalic topography, whereby the stimulating electrode is oriented in any of three planes, horizontal, sagittal or frontal, in reference to a central, arbitrarily fixed point within the cranium, avoiding the necessity of depending on variable external contours for points of reference.

The instrument itself (fig. 1), fully described in Horsley and Clarke's original paper, resembles a cage which is fitted on the head of the animal and fixed in place by means of pivots inserted in the external auditory meatus and by clamps that grasp the lower margin of the orbit and the oral surface of the maxilla. A line drawn between these points of attachment, that is, the center of the external auditory meatus and the lower margin of the orbit, coincides with the basal horizontal plane of the instrument. It is not convenient to use this as one of the orienting planes, however, since it passes through the inferior surface of the pons, which is too low for our purpose; therefore, a plane approximately

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6. Ashizawa, R., and Lewy, F. H.: Folgen isolierter Reizung und Ausschaltung des Streifenhügelkopfes bei der Katze, Ztschr f. d. ges. exper. Med. **66**:157, 1929.

7. Horsley, V., and Clarke, R. H.: The Structure and Functions of the Cerebellum Examined by a New Method, Brain **31**:45, 1908.

10 mm. higher is reached by raising the frame of the instrument one third of the distance between the interaural line and the vertex. This may be done by the proper use of adjusting screws and sliding scales, and places the instrument so that the lower margin of its frame coincides with the zero horizontal orienting plane. The frontal plane is perpendicular to the zero plane along the interaural line, and to the midsagittal plane. To make the midsagittal plane of the instrument correspond to that of the brain the former must be properly centered on the head.

The framework of the machine is fitted with carriers whereby a needle electrode may be introduced into the brain substance along either vertical or horizontal lines, these carriers being provided with scales that make it possible to determine the position of the tip of the needle at any time in relation to the zero point, or the point of intersection of the frontal, horizontal and midsagittal planes. Thus, the needle carrier may be set at a definite spot in relation to the midsagittal and frontal planes, for instance, 1 mm. anterior to the latter and 2 mm. to the right of the former, in

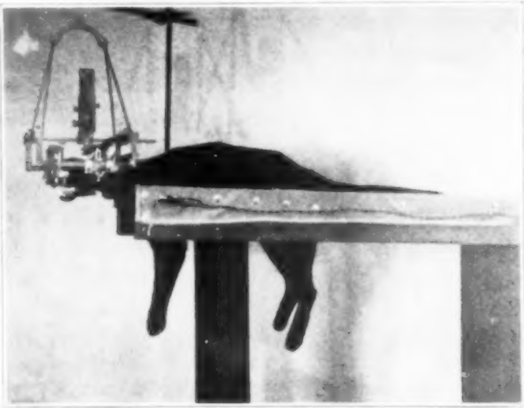

Fig. 1.—The Horsley-Clarke stereotaxic instrument and the manner of supporting the animal during the experiment.

a vertical position. The needle is then, by use of a rack and pinion mechanism, made to descend into the brain substance until the desired point is reached as indicated by the scale, for instance, to a level 3 mm. below the zero horizontal plane. By means of this arrangement it is possible to explore any area in the brain stem millimeter by millimeter, always being certain as to the location of points stimulated in relation to points already reached by the needle.

In order to guard against the possibility of escape of current, the needle electrodes used in this work were of the bipolar type, the work of Horsley and Clarke having shown such electrodes to be reliable in this regard, whereas with the use of unipolar stimulating electrodes one is always confronted with the likelihood of inaccurate results due to "escapes." The needles originally used by these workers, being insulated with glass, were very delicate, and it was found much more convenient to construct electrodes of enameled nichochrome wire. Suitable lengths of 22 and 28 gage wire are drawn out so as to be perfectly straight and fastened together and reinsulated with a chlorinated rubber solution. The larger wire gives to the needle the stiffness necessary for penetration of the dura, while the smaller furnishes the second pole of the electrode. After the insulating material is thoroughly dried and hardened, the tip of the needle is ground to a point suitable for

facilitating its entry and preventing undue trauma from tearing or cutting. This operation also permits the adjustment of the bare tips of the electrodes to within a millimeter of one another. A needle made of wires of the sizes mentioned measures less than a millimeter through its greatest diameter, and, aside from the small but unavoidable hemorrhage usually produced, causes very slight damage to the brain substance in passing through it. Such needles may also be sterilized without injury by immersion in alcohol.

The cats used in these experiments were anesthetized with ether, the calvarium was opened over a suitable area, and the stereotaxic instrument was adjusted. The animal was then suspended in a hammock through which the legs protruded, the instrument being supported by an arrangement that permitted the animal to swing its head from side to side (fig. 1). A gauze mask was fastened over the face for the administration of the anesthetic. The needle was now inserted through the dura, without cutting or removing the latter, at the most anterior point of the area to be explored, and 1 or, more usually, 2 mm. from the midsagittal plane. The most dorsal point of stimulation was usually at, or 1 mm. below, the zero horizontal plane, successive stimulations being made at 1 or 2 mm. intervals as the needle was passed down into the substance of the brain stem. The response elicited at each point was carefully noted and recorded, and after the needle had reached a sufficient depth it was withdrawn and inserted again at a spot 1 or sometimes 2 mm. lateral to its previous location. This procedure was repeated until a frontal plane had been explored for a distance of from 5 to 7 mm. from the midline. Then the needle was moved 1 or 2 mm. caudalward and that frontal plane explored in the same manner. One may proceed in this way until several hundred separate points have been stimulated, always beginning anteriorly and working posteriorly so as to leave the descending tracts and fiber connections caudal to the area under exploration intact.

In one group of experiments the exploration began far forward in the preoptic area and extended, millimeter by millimeter, caudalward through the hypothalamus, subthalamus and the extreme ventral part of the thalamus; i. e., that part of the thalamus which lies below the zero horizontal plane. The extent of the exploration in a caudal direction was limited by the time available for the experiment, and when it began far forward it did not usually extend caudalward beyond the level of the mamillary body. In another group of experiments the caudal part of the thalamus, the subthalamus, the mesencephalon and the rostral part of the pons were explored. In still another group the exploration, after removal of the bony tentorium, included the posterior part of the mesencephalon, the pons and the medulla at the level of the trapezoid body.

For stimulation, a Harvard coil was used, with one or two dry cells delivering from 1.5 to 2 amperes through the primary circuit. Through a series of preliminary experiments an approximate minimal stimulus for the response under consideration was found to be furnished by a coil separation of 13 cm., with the secondary coil set at 45 degrees, and this setting of the coil was maintained throughout the investigation.

At the close of an experiment the animal was killed, and the brain was removed, hardened in a diluted solution of formaldehyde U. S. P. (1:10) and prepared for microscopic study. In the latter procedure the brain stems of the experimental animals were sectioned and stained by Weil's method and with iron hematoxylin. In such preparations the track of the needle is visible owing to the presence of blood in the small canal left when the needle was withdrawn. It was found possible, by allowance for shrinkage, to determine quite accurately the points stimulated, since their relations to one another were known by the different settings of

the needle on the instrument. These determinations were most readily made when the sections were cut in a plane parallel to that along which the track of the needle passed. The lowest point stimulated corresponded to the ventral end of the puncture, and the others were spaced at the proper intervals upward along the track. However, if the plane of section was not parallel to the plane of the punctures, the material was still suitable, the points of stimulation along a single needle track being arrived at by measuring upward from its most ventral point until the zero horizontal plane was reached. This level was accurately determined by the study of three series of frontal sections of cat brains into which straight wires had been inserted horizontally, along this plane, by the use of the stereotaxic instrument. Each of these sections showed a row of holes along the zero horizontal line, which had been left when the wires were withdrawn after embedding the brain in celloidin.

OBSERVATIONS

Description of the Responses Obtained.—It was seen early in the course of the experiments that the so-called tegmental response recognized and described by workers who stimulated the cut surface of the brain could readily be elicited by stimulation of the interior of the brain stem of an animal with the forebrain intact. This response consists of a flexion of the fore limb of the side stimulated, an extension of the contralateral fore limb, a curving of the neck and trunk in an arc concave on the side stimulated and a turning of the head toward the side stimulated. Movements of the hind limbs seem to vary. Often both are flexed; sometimes the contralateral one is flexed and the ipsolateral extended; usually they are swung toward the stimulated side by tilting the pelvis as the back is curved. The movements of the fore limbs are slow, and the resulting posture of ipsolateral flexion and contralateral extension may be maintained for some time after the cessation of the stimulus. The response as observed by us is best described in the following protocol:

Cat 104: The point of the needle was located 3 mm. anterior to the zero frontal plane, 2 mm. to the right of the midline and 2 mm. below the zero horizontal plane. Faradic stimulation caused flexion of the ipsolateral fore limb at the shoulder and elbow and elevation of the scapula. This movement developed slowly and was maintained for several seconds after cessation of the stimulus. Both hind limbs flexed slightly, the right more than the left. There was a slight movement, resembling stepping, in the right hind limb following stimulation. The head was turned to the right, and there slowly developed, on prolonged stimulation, a curvature of the entire spine, with the concavity to the right. After stimulation had ceased for some time the animal held its head turned to the left, maintaining it in that position steadily. There was dilatation of the pupils on stimulation.

On repeated stimulation there were a marked throwing forward and flexion of the ipsolateral fore limb and a swinging out to the right of both hind limbs, the latter due to a rotation of the spine and a tilting of the pelvis. There was an extension of the left fore limb accompanying these movements.

Examination of the brain at autopsy showed the needle to have entered the mesencephalon at the anterior border of the superior colliculus. On microscopic

examination it was found that the point of stimulation was dorsolateral to the capsule of the red nucleus at the level of exit of the third nerve.

These observations, so far as the response is concerned, have been repeated many times in a large series of cats. In this case a single point was stimulated, but in most of the experiments a large area of brain stem was explored, as many as 350 points being stimulated in some individual animals. Sometimes only parts of the complete typical tegmental response were elicited, for example, a turning of the head without limb movements or complete curving of the back, or flexion of the ipsolateral fore limb without the other movements. Occasionally, the curving of the back occurred without any concomitant turning of the head toward the side stimulated. In some cases, when the neck was curved toward the stimulated side the face was twisted in the opposite direction. This twisting corresponds with the rotation of the head described by Környey,[4] from his experiments in stimulating the cut surface of the brain stem. Many times, additional responses of varying character were observed, frequently superimposed on the typical tegmental response, sometimes apparent by themselves. Among these were: flexion of the contralateral fore limb; swinging of the hind limbs contralaterally; dilatation or, more rarely, constriction of the pupils; erection of hairs of the back; cries; spreading of the digits; contraction of facial and masticator muscles; cessation of respiration; acceleration of respiration; movement of the eyes, and, rarely, urination.

In certain cases, in some animals, the typical response would be extremely marked. In these the responses were swift and violent, the body curving to such an extent and the head snapping ipsolaterally with such violence as almost to dislodge the animal from its suspended position; indeed, if the animal were not prevented by the arrangement of the hammock, one could believe that the back would curve until the head touched the base of the tail. Accompanying this, the ipsolateral fore limb may be markedly flexed, usually with the digits spread and claws protruded, and often crossing over above the contralateral limb, which meanwhile assumes a pronounced rigidity of all its muscles. At such times there may also be erection of hairs along the back, cries, extreme dilatation of the pupils and contraction of the facial muscles, with flexion of the hind limbs, which may be swung either toward or away from the side stimulated. These extra responses do not necessarily accompany only the exaggerated responses, but often appear when the response is mainly of a mild, typical variety.

For analysis of the material contained in the lengthy protocols of the seventy-four experiments and that derived from the microscopic study, a series of different types of tables was constructed, some representatives of which are included in this paper. It was first necessary

TABLE 1.—*Data on Cat 151* *

Position According to Instrument	Structures Stimulated as the Needle Was Pushed Ventralward From the Zero Horizontal Plane	1	2	3	4	5		6	7	8	9	10	11	12	13	14	15		16
						R	L										R	L	
A = 0; L = 2; H = −1	Central gray																		
H = −2	Dorsal medial reticular area	X	+	+	..	..	+	..	±	..	..	+	..	..	..	..	+	+	..
H = −3	Central fasciculus	X	+	+	..	..	+	..	±	..	..	+	..	+	..	..	+	+	..
H = −4	Medial part of brachium conjunctivum	X	+	+	..	..	+	..	±	..	..	+	..	..	..	..	+	+	..
H = −5	Middle medial reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −6-8	Region of descending limb of branchium conjunctivum	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
A = 0; L = 3; H = −1	Tectospinal fibers																		
H = −2	Dorsal medial reticular area	..	..	..	..	..	..	..	+	..	..	..	..	..	..	..	+	+	+
H = −3	Middle medial reticular area	X	+	+	+	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −5	Brachium conjunctivum region	+	+	+	+	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −6-7	Ventral medial reticular area	+	+	+	+	..	..	..	..	..	..	+	..	..	..	..	+	+	..
H = −8-9	Region of ventral reticular nucleus and dorsal medial lemniscus	+	+	+	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
A = 0; L = 4; H = −1	Spinotectal fibers																		
H = −2	Dorsal lateral reticular area	..	..	..	..	..	..	..	±	..	..	..	..	..	..	..	+	+	..
H = −3	Middle lateral reticular area	X	+	+	+	..	..	..	..	..	..	..	..	+	..	..	+	+	..
H = −4	Lateral brachium conjunctivum	X	+	+	+	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −5-7	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −8	Rubrospinal tract region	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −9	Spinothalamic tract region	±	±	±	..	..	..	..	..	..	..	±	..	..	..	..	±	±	..
A = 0; L = 5; H = −2	Spinotectal fibers																		
H = −3	Middle lateral reticular area	X	+	+	..	..	..	..	±	..	+	..	..	+	..	..	+	+	..
H = −4	Middle lateral reticular area	+	+	+	+	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −5	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −6-8	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	+	..	..	+	+	..
H = −9	Spinothalamic tract region	..	..	..	..	..	..	..	..	..	..	+	..	+	..	..	+	+	..
A = −1; L = 2; H = −1	Central gray and tectospinal fibers																		
H = −2-3	Central fasciculus	X	+	+	..	+	+	..	+	..	..	..	..	±	..	..	+	+	..
H = −4	Reticular area lateral to decussation of brachium conjunctivum	+	+	..	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −5	Ventral medial reticular area	+	+	..	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −5-8	Region of descending limb of brachium conjunctivum	+	+	..	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
A = −1; L = 3; H = −1	Tectospinal fibers																		
H = −2	Dorsal medial reticular area	..	..	+	..	..	..	..	+	..	..	..	..	..	..	..	+	+	..
H = −3	Upper middle reticular area	X	+	±	+	+	+	..	±	..	+	..	..	..	..	..	+	+	..
H = −4	Middle reticular area	X	+	..	..	..	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −5	Brachium conjunctivum region	+	+	..	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −6-7	Ventral reticular area	+	+	..	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −8	Lateral to descending brachium conjunctivum fibers	+	+	+	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −9	Lateral ventral reticular nucleus	+	+	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
A = −1; L = 4; H = −1	Inferior colliculus and spinotectal fibers																		
H = −2	Dorsal lateral reticular area	..	..	..	..	..	+	..	+	..	..	..	..	..	..	..	±	±	..
H = −3	Upper middle lateral reticular area	X	+	+	..	..	+	+	+	..	..	..	..	..	..	..	+	+	..
H = −4-5	Middle lateral reticular area	+	+	+	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −6	Ventral reticular area	+	+	+	..	+	+	..	..	..	+	+	..	..	..	..	+	+	..
H = −7	Rubrospinal tract region	+	+	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
H = −8	Rubrospinal tract region	⊕	..	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
H = −9	Spinothalamic tract region	+	+	+	..	+	+	..	..	..	..	+	+	..	..	..	+	+	..

A = −1; L = 5; H = −1-2	Spinotectal fibers																		
H = −3-4	Dorsal and middle lateral reticular area	..	..	..	..	..	+	..	±	..	..	..	..	..	..	..	+	+	..
H = −5	Middle lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −6	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Rubrospinal tract region	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −8	Rubrospinal and spinothalamic regions	⊕	+	+	..	..	+	..	..	..	..	+	..	+	..	..	+	+	..
H = −9	Spinothalamic region	⊕	+	+	..	..	+	..	..	..	..	+	..	+	..	..	+	+	..
A = −2; L = 2; H = −1-2	Central gray																		
H = −3	Dorsal medial reticular area	..	..	..	..	..	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −4	Upper middle medial reticular area	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	+	+	..
H = −5	Middle medial reticular area	+	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±	±	..
H = −6-7	Ventral medial reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −8	Region of descending brachium conjunctivum	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −9	Region of ventral reticular nucleus	+	+	+	..	+	+	..	..	+	..	..	+	..	..	..	+	+	..
A = −2; L = 3; H = −1-2	Tectospinal fibers																		
H = −3	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −4-5	Middle medial reticular area	±	..	..	..	..	..	..	..	..	+	..	..	..	..	..	+	+	..
H = −6-7	Ventral medial reticular area	+	+	+	..	+	+	..	..	..	+	..	..	..	..	..	+	+	..
H = −7-8	Ventral medial reticular area, near rubrospinal region	+	+	..	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −9	Region of ventral reticular nucleus	+	+	..	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
A = −2; L = 4; H = −3	Inferior colliculus																		
H = −4	Brachium conjunctivum fibers	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −5	Dorsal lateral reticular area	±	±	±	..	±	±	..	..	..	±	..	..	..	..	..	±	±	..
H = −6	Middle lateral reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	+	..	+	..	..	..	+	+	..
H = −8	Rubrospinal region	+	+	+	+	+	+	..	..	..	+	+	+	..	..	..	+	+	..
H = −9	Spinothalamic region	+	+	+	+	+	+	..	..	..	+	+	+	..	..	..	+	+	..
A = −2; L = 5; H = −2	Inferior colliculus																		
H = −5	Middle lateral reticular area	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −6	Ventral reticular and brachium conjunctivum fibers	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Ventral lateral reticular area	+	+	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
H = −8	Rubrospinal region	+	+	±	..	+	+	..	..	..	..	+	+	..	..	..	+	+	..
H = −9	Spinothalamic region	±	..	..	..	..	..	..	..	..	..	+	..	..	+	..	..	..	..
A = −3; L = 2; H = −1	Central gray																		
H = −2-3	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±	±	..
H = −4-5	Middle medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±	±	+
H = −6	Ventral medial reticular area	±	±	±	..	±	±	..	..	..	..	..	..	..	..	..	±	±	..
H = −7	Ventral medial reticular area	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −8-9	Lateral to descending brachium conjunctivum	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
A = −3; L = 3; H = −1	Inferior colliculus																		
H = −2-3	Dorsal brachium conjunctivum fibers	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
H = −4-5	Dorsal and middle medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
H = −6	Ventral medial reticular area	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7-8	Ventral medial reticular area	+	+	+	..	+	+	..	..	±	..	+	+	..	..	..	+	+	..
H = −9	Same, but farther ventral	+	+	..	..	+	+	..	..	+	..	+	+	..	..	..	+	+	..

TABLE 1.—*Data on Cat 151* *—*Continued*

Position According to Instrument	Structures Stimulated as the Needle Was Pushed Ventralward From the Zero Horizontal Plane	1	2	3	4	5 R	5 L	6	7	8	9	10	11	12	13	14	15 R	15 L	16
A = −3; L = 4; H = −1-3	Inferior colliculus and brachium conjunctivum																		
H = −4	Lateral brachium conjunctivum fibers	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
H = −5	Middle lateral reticular area	±	..	..	..	..	..	..	..	..	..	..	..	..	..	+	..	..	+
H = −6	Middle lateral reticular area	+	+	+	..	+	+	..	..	..	+	..	..	..	+	..	+	+	..
H = −7	Ventral lateral reticular area	+	+	+	..	+	+	..	..	..	+	..	..	..	+	..	+	+	..
H = −8-9	Rubrospinal region	+	+	+	..	+	+	..	..	..	..	..	..	..	+	..	+	+	..
H = −10	Spinothalamic region	±	±	±	..	..	..	..	..	..	..	..	..	..	..	..	±	±	..
A = −3; L = 5; H = −1-4	Inferior colliculus, lateral lemniscus and brachium conjunctivum																		
H = −5	Dorsal lateral reticular area																		
H = −6	Middle lateral reticular area	±	±	±	..	±	±	..	..	..	..	..	..	..	..	..	±	±	..
H = −7	Ventral lateral reticular area	+	+	+	+	+	+	..	..	..	+	..	..	..	+	..	+	+	..
H = −8	Rubrospinal region	+	+	+	+	+	+	..	..	..	..	..	..	..	+	..	+	+	..
H = −9-10	Rubrospinal and spinothalamic regions	+	+	+	..	+	+	..	..	..	..	..	..	..	+	..	+	+	..
A = −4; L = 2; H = −1-2	Central gray																		
H = −3	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
H = −4	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −5	Middle medial reticular area	±	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6	Middle medial reticular area	+	+	+	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Ventral medial reticular area	+	+	+	+	+	+	..	..	..	..	..	..	..	+	..	+	+	..
H = −8-10	Ventral medial reticular area	+	+	..	..	+	+	..	..	..	..	..	..	..	+	..	+	+	..
A = −4; L = 3; H = −1-3	Inferior colliculus, central gray																		
H = −4	Dorsal brachium conjunctivum fibers																		
H = −5	Dorsal reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6	Middle reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −7	Middle reticular area	±	±	±	..	..	..	..	..	..	..	+	..	..	+	..	±	±	..
H = −8	Ventral reticular area	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −9	Ventral reticular area	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
A = −4; L = 4; H = −3	Inferior colliculus																		
H = −4	Brachium conjunctivum																		
H = −5	Dorsal lateral reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6	Middle lateral reticular area	+	..	..	..	..	+	..	..	..	..	..	..	..	..	..	+	+	+
H = −7	Middle lateral reticular area	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −8	Ventral reticular and rubrospinal region	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −9	Rubrospinal region	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −10	Spinothalamic region	+	+	±	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
A = −4; L = 5; H = −3	Inferior colliculus																		
H = −4	Brachium conjunctivum region	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±
H = −5	Dorsal lateral reticular area	+	+	..	+	..	+	..	..	..	..	..	..	..	..	..	±	±	..
H = −6	Middle lateral reticular area	+	+	..	+	..	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Middle lateral reticular area	+	+	..	..	+	+	..	..	..	..	+	+	..	+	..	+	+	..
H = −8	Rubrospinal region	+	+	±	..	+	+	..	..	..	..	..	+	..	+	..	+	+	..
H = −9	Rubrospinal and spinothalamic region	+	+	±	..	+	+	..	..	..	..	..	+	..	+	..	+	+	..
H = −10	Spinothalamic region	+	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	..

A = −5; L = 2; H = −1-3	Central gray																		
H = −4	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+
H = −5	Dorsal medial reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6	Middle medial reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −7-8	Middle and ventral medial reticular area	+	..	+	..	..	+	..	..	..	..	+	..	..	..	..	..	..	+
H = −9	Ventral medial reticular area	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −10	Ventral medial reticular area	+	..	..	..	..	+	..	..	..	..	..	..	+	..	..	+	+	..
A = −5; L = 3; H = −1-4	Inferior colliculus and dorsal reticular area																		
H = −5	Dorsal reticular area	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6-7	Middle reticular area	±	±	±	..	..	..	..	..	..	..	±	..	..	..	..	±	±	..
H = −8	Ventral reticular area	±	±	±	..	..	..	..	..	..	..	±	..	..	+	..	±	±	..
H = −9	Ventral reticular area and medial rubrospinal fibers	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −10	Rubrospinal region and dorsal trapezoid fibers	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
A = −5; L = 4; H = −1-3	Inferior colliculus and brachium conjunctivum																		
H = −4	Ventral to brachium conjunctivum	±	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −5	Dorsal lateral reticular area	±	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	+
H = −6	Middle lateral reticular area	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Middle lateral reticular area and rubrospinal region	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −8-9	Rubrospinal region	+	+	+	..	+	+	..	..	..	..	..	+	..	..	..	+	+	..
H = −10	Dorsal trapezoid region	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
A = −5; L = 5; H = −1-2	Inferior colliculus																		
H = −3	Brachium conjunctivum region	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±	±	..
H = −4	Dorsal lateral reticular area	±	..	..	..	..	..	..	..	..	..	..	..	..	..	..	±	±	..
H = −5	Dorsal lateral reticular area	+	+	..	+	..	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −6	Middle lateral reticular area	+	+	..	+	..	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Ventral lateral reticular area and rubrospinal region	+	+	..	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −8	Reticular area medial to lateral lemniscus	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
H = −9	Lateral dorsal trapezoid region	+	+	+	..	+	+	..	..	..	+	+	+	+	+	..	+	+	..
H = −10	Lateral trapezoid region	+	..	..	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
A = −6; L = 4; H = −1-4	Inferior colliculus and brachium conjunctivum																		
H = −5	Dorsal lateral reticular area	+	+	..	+	..	..	..	..	..	..	..	..	..	..	..	+	+	..
H = −6	Middle lateral reticular area	+	+	..	+	..	+	..	..	..	..	..	..	..	..	..	+	+	..
H = −7	Rubrospinal region and middle reticular area	+	+	+	..	+	+	..	..	..	+	+	..	..	..	..	+	+	..
H = −8	Rubrospinal region	+	+	+	..	+	+	..	..	..	+	+	..	..	..	..	+	+	..
H = −9-10	Dorsal trapezoid region	+	+	+	..	+	+	..	..	..	+	+	..	..	..	..	+	+	..
A = −6; L = 5; H = −1-4	Inferior colliculus and brachium conjunctivum																		
H = −5	Middle lateral reticular area	+	+	..	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
H = −6	Middle lateral reticular area and rubrospinal fibers	+	+	..	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
H = −7	Rubrospinal region	+	+	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..	..
H = −8-9	Ventral rubrospinal region and dorsal trapezoid body	±	±	±	..	..	..	..	..	..	..	±	..	..	..	..	±	±	..
H = −9-10	Trapezoid region	±	±	±	..	..	..	..	..	..	±	±	..	..	..	..	±	±	..

* The symbols used in tables 1 and 2 are as follows: 1, head turns to side stimulated; 2, trunk curves, concavity toward side stimulated; 3, flexion of ipsolateral fore limb; 4, extension of contralateral fore limb; 5, flexion of the hind limbs; 6, hind limbs swing toward stimulated side; 7, head turns away from stimulated side; 8, flexion of contralateral fore limb; 9, erection of hairs; 10, contraction of facial or masticator muscles; 11, spreading of digits; 12, cries; 13, cessation of respiration; 14, acceleration of respiration; 15, dilatation of the pupils; 16, eye movements; +, positive response; X, neck retracted toward side stimulated; ⊕, head drawn back. The movements belonging particularly to the typical tegmental response are indicated in the first six columns of tables 1 and 2. The position according to the instrument was recorded as follows: A, number of millimeters caudal to the zero horizontal plane; L, number of millimeters to the right of the midline; H, number of millimeters below the zero horizontal plane.

to make a table for each cat to show the regions stimulated, their approximate level in the brain stem and the responses elicited. Table 1 is an example of this type. When this was done it was a natural step to make a general table for each stimulated area, indicating the responses obtained from this region in each cat. Table 2 illustrates this for the region of the rubrospinal tract. From these, with reference to the original protocols, one could tabulate the purely typical responses in relation to the regions from which they were obtained (this material will shortly be described). Finally, table 3 summarizes the chief areas from which typical responses may be elicited, together with the numbers of the cats giving such responses from these regions.

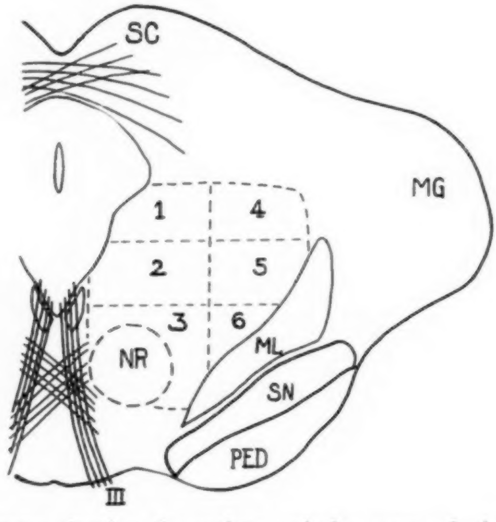

Fig. 2.—Diagram showing the various reticular areas: *1*, the dorsal medial reticular area, including the central tegmental fasciculus; *2*, the middle medial reticular area; *3*, the ventral medial reticular area; *4*, the dorsal lateral reticular area; *5*, the middle lateral reticular area; *6*, the ventral lateral reticular area; *SC*, the superior colliculus; *MG*, the medial geniculate body; *NR*, the red nucleus; *ML*, the medial lemniscus; *SN*, the substantia nigra, and *PED*, the peduncle.

In table 1 and in this discussion frequent reference will be made to various areas of the reticular formation. This has been done where it has not been deemed feasible to refer to specific structures that may lie within this region. What we mean by reticular area may best be described with reference to figure 2, in which its boundaries are indicated by dotted lines and its various parts are numbered. As shown, it lies dorsal and lateral to the red nucleus and is divided by a vertical line into medial and lateral reticular areas and by two horizontal lines into dorsal, middle and ventral reticular areas. Region *1* has been referred to as the dorsal medial reticular area, including the central

tegmental fasciculus; *2* is the middle medial reticular area; *3* is the ventral medial reticular area; *4*, *5* and *6* refer to similar divisions of the lateral area. At more caudal levels the same idea may be extended and adjusted to the changing contours of the brain stem.

TABLE 2.—*Rubrospinal Region*

Cat	Approximate Level (Fig. 3)	Comment	1	2	3	4	5 R	5 L	6	7	8	9	10	11	12	13	14	15 R	15 L	16
133	Line 5	....	±	..	..	..	..	..	..	..	..	+	+	..	..	..	..	+	+	..
	Line 5-6	Perhaps peduncle fibers	..	..	..	..	..	+	..	..	+	..	..	..	..	..	..	+	+	..
	Line 5-6	Plus medial lemniscus	..	..	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
	Line 6	Perhaps peduncle fibers	..	..	..	..	..	+	..	+	+	..	..	..	+	..	..	+	+	..
134	Line 4	....	+	..	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5	....	+	..	+	..	+	..	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5-6	....	+	..	+	..	+	..	..	..	..	..	..	..	..	..	..	..	..	..
136	Line 4	....	±	..	..	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
	Line 4-5	....	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 4-5	....	X	+	+	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5-6	....	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 6	....	+	..	+	..	+	+	..	..	+	+	..	..	..	..	..	+	+	..
	Line 6-7	....	+	+	+	..	+	+	..	..	+	+	..	..	..	..	..	+	+	..
137	Line 5	....	X	..	+	..	+	+	..	+	..	..	..	..	..	..	..	+	+	..
	Line 5-6	....	+	+	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5-6	....	X	+	+	..	+	+	+	..	..	..	..	..	..	..	..	+	+	..
	Line 6	....	+	+	+	..	+	+	+	..	..	..	..	..	..	..	..	+	+	..
	Line 6-7	....	X	..	+	..	..	..	..	..	..	..	+	..	..	..	+	..	..	..
	Line 6-7	....	+	+	+	..	+	+	+	..	+	+	..	..	..	..	..	+	+	..
	Line 6-7	....	..	..	+	..	..	..	..	..	..	..	+	..	..	..	..	±	±	..
	Line 7	....	+	+	+	+	+	+	..	..	..	+	..	+	+	..	..	..	..	..
129	Line 5	....	..	..	+	..	..	..	..	+	..	..	..	..	..	..	..	+	+	..
	Line 5-6	Perhaps peduncle fibers	..	..	..	..	+	+	..	+	+	..	..	..	..	..	..	..	..	..
141	Line 5	....	+	+	+	+	+	+	..	..	..	..	..	..	..	+	..	+	+	..
	Line 5-6	....	..	+	+	+	..	+	..	+	..	..	..	+	..	..	..	+	+	..
	Line 6	....	..	..	±	..	+	+	..	+	..	..	..	+	..	..	..	+	+	..
	Line 6-7	....	+	+	+	+	+	+	..	..	..	..	+	+	..	..	..	+	+	..
	Line 7-8	....	X	..	+	..	..	+	..	..	..	..	..	..	..	..	..	±	±	..
151	Line 4-5	....	+	+	+	+	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5	....	+	+	+	..	+	+	..	..	..	..	+	..	..	..	..	+	+	..
	Line 5-6	....	+	+	+	..	+	+	+	..	..	..	..	..	..	..	..	+	+	..
	Line 5-6	Plus spinothalamic fibers	⊕	+	+	..	..	+	..	..	..	..	+	..	+	..	..	+	+	..
	Line 5-6	....	+	+	+	+	+	+	..	..	..	..	+	..	..	+	..	+	+	..
	Line 6	Plus dorsal trapezoid fibers	+	+	+	..	+	+	..	..	..	..	+	..	..	+	..	+	+	..
	Line 6-7	....	+	+	+	..	+	+	+	..	..	..	..	+	..	..	..	+	+	..
	Line 6-7	....	+	+	+	..	..	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 7	....	+	+	+	..	+	+	..	..	..	+	+	..	..	..	..	+	+	..
169	Line 3-4	....	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	+	±	..
	Line 4-5	....	+	..	..	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
170	Line 4-5	....	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	±	±	..
	Line 5-6	....	+	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	+	..
171	Line 3-4	....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	+	+
	Line 5	....	±	..	+	..	+	+	..	..	..	..	..	..	..	..	..	+	+	..
	Line 5-6	....	+	+	+	..	..	+	..	..	..	..	..	..	..	..	..	..	..	..
172	Line 5	....	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	+	+	..
173	Line 5-6	....	+	..	..	+	..	..	..	..	..	..	+	..	..	+	..	+	+	..

Regions Giving Typical Responses.—In describing the material from this series of experiments we have already outlined in a general way the various responses that may be obtained from stimulation of the mesencephalic tegmentum, and we propose now to consider the evidence provided by the microscopic sections as to the regions which gave the typical response. In still another section we shall describe and discuss

responses elicited from other areas. One must bear in mind, then, that in the data about to be considered the responses contained the elements of the usual typical response, namely, flexion of the ipsolateral fore limb, turning of the head or retraction of the neck ipsolaterally and curving of the spinal column with the concavity toward the stimulated side. There may be additional reactions accompanying these in any individual animal, but such responses will not be remarked on at the present moment.

Cat 104 gave a typical response from the reticular area slightly dorsolateral to the red nucleus at the level of the exit of the third nerve (between levels *2* and *3* of figure 3), while cat 107 gave it from the reticular area between the red nucleus and

TABLE 3.—*Typical Responses Elicited by Stimulation of the Brain Stem*

Area from Which Response Is Obtained	Cats
Central fasciculus	109, 110, 114, 116, 117, 120, 129, 131, 133, 135, 136, 141, 151, 169, 170, 171, 174
Dorsal medial reticular area	110, 122, 129, 131, 132, 133, 135, 136, 141, 151, 171, 174
Middle medial reticular area	118, 129, 131, 133, 134, 135, 136, 141, 151, 169, 170, 171, 173
Ventral medial reticular area	122, 129, 131, 133, 134, 135, 136, 137, 141, 151, 169, 170, 171, 173
Dorsal lateral reticular area	124, 128, 129, 131, 132, 133, 134, 136, 151, 171, 172, 173, 174
Middle lateral reticular area	124, 128, 129, 131, 132, 133, 134, 135, 136, 151, 171, 172, 173
Ventral lateral reticular area	128, 129, 131, 132, 133, 134, 135, 136, 137, 141, 151, 173
Brachium conjunctivum—anterior part of capsule of red nucleus, near line 1, figure 3	114, 135, 136, 140, 147
Brachium conjunctivum region, caudal to red nucleus, including reticular area	124, 137, 141, 151, 171
Region of descending limb of brachium conjunctivum, including reticular area	134, 151
Region of spinothalamic tract, including probably fibers of reticular area	128, 134, 135, 136, 137, 141, 151
Region of medial lemniscus, plus reticular area or spinothalamic fibers	128, 135
Region of rubrospinal tract, including reticular area	136, 137, 141, 151, 171
Anterior part of red nucleus	136

the lateral tegmental nucleus, determination of its exact spot being obscured somewhat by the presence of a rather diffuse lesion. Cat 109 gave the response from the region of the central tegmental fasciculus at the level of line *3* (fig. 3), and again from the same area somewhat farther caudalward. In cat 110, it was observed to come from stimulation of the central tegmental fasciculus at the level of line *2*, from the dorsal reticular area of approximately the same level and from the dorsal and middle reticular areas at the level of line *4*. In cat 114, it was also elicited from the central tegmental fasciculus region at a level between lines *1* and *2*, and from the fibers of the anterior capsule of the red nucleus at nearly the same region. The central tegmental fasciculus and the reticular formation just ventral to it again produced the typical response in cat 116 at level *3*, while in cat 117 the same region gave it at level *2*. Cat 118 gave the response on stimulation of the reticular area lateral and dorsal to the red nucleus, and cat 120 gave it from the central tegmental fasciculus over an area extending from lines *1* to *3*. In cat 122, it came from the dorsal and middle reticular areas at the level of line *2*, and from the lower reticular

area lateral to the red nucleus. In cat 124, the response came from the reticular area just ventral to the inferior colliculus, between levels *6* and *7*, from the reticular area medial to the spinotectal tract at the level of line *5* and from the brachium conjunctivum region and lateral reticular area medial to the nucleus of the lateral lemniscus. In cat 128, it came from the lateral reticular area at the level of the juncture of the colliculi, from the reticular area in the region of the spinothalamic tract near the same level and from the lateral reticular area at level *4*. In cat 129, the response came from the central tegmental fasciculus at level *2*, from the medial and lateral reticular areas at level *4* and the same at level *6*. In cat 131, it came from the central reticular area at level *2*, from the reticular area lateral and dorsolateral to the red nucleus, from the lateral border of the red nucleus, from the central tegmental fasciculus region at level *6*, from the reticular

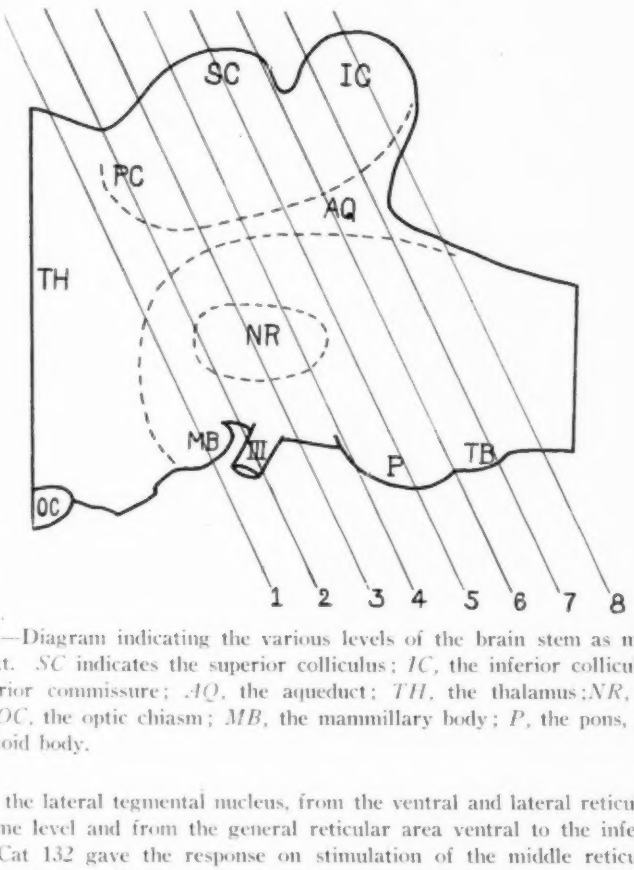

Fig. 3.—Diagram indicating the various levels of the brain stem as mentioned in the text. *SC* indicates the superior colliculus; *IC*, the inferior colliculus; *PC*, the posterior commissure; *AQ*, the aqueduct; *TH*, the thalamus; *NR*, the red nucleus; *OC*, the optic chiasm; *MB*, the mammillary body; *P*, the pons, and *TB*, the trapezoid body.

area near the lateral tegmental nucleus, from the ventral and lateral reticular areas of the same level and from the general reticular area ventral to the inferior colliculus. Cat 132 gave the response on stimulation of the middle reticular area between levels *2* and *3*, the reticular area at level *4*, the lateral reticular area between levels *4* and *5*, the reticular areas in general between levels *5* and *6* and the lateral reticular area medial to the lateral lemniscus. In cat 133, the response came from the dorsal and ventral reticular areas at a level between lines *2* and *3*, from the reticular area near the lateral tegmental nucleus, from the central tegmental fasciculus, just caudal to the red nucleus, from the lateral reticular area at level *5*

and from the general reticular areas between lines *5* and *6*. In cat 134, it came from the general reticular areas at level *4*, from the reticular area caudal to the red nucleus, from the region of the descending limb of the brachium conjunctivum, from the reticular area including the rubrospinal and spinothalamic fibers near the same level, and from the general reticular areas, including the spinothalamic fibers between levels *5* and *6*. In cat 135, it came from the region of the H_1 field near level *1*, from the central tegmental fasciculus at level *2*, from the brachium conjunctivum fibers ventral to the foregoing level, from the dorsal reticular area slightly caudal to this level, from the reticular area lateral to the red nucleus (level *3*), from the general reticular areas between levels *3* and *5* and from the middle and ventral reticular areas, including the spinothalamic fibers at a level between lines *5* and *6*. In cat 136, the response came from the central tegmental fasciculus region at a level slightly rostral to line *2*, from fibers of the anterior capsule of the red nucleus (brachium conjunctivum and H field) at the same level, from the central reticular area and the central tegmental fasciculus at level *2*, from the reticular area dorsolateral to the red nucleus, from the central fasciculus at level *3*, from the most anterior cells of the red nucleus with the fibers among which they lie, from the general reticular area at levels *4* and *5*, including fibers of the rubrospinal and spinothalamic tracts, and from the middle and ventral lateral reticular areas near level *7*. In cat 137, the response came from the reticular region lateral to the fibers of the anterior capsule of the red nucleus and spinothalamic fibers, but only parts of the response were obtained from here back to the neighborhood of level *6*, where the lateral reticular area and rubrospinal region produced the response, along with the spinothalamic fibers; caudal to this level the response was elicited from the ventral and lateral reticular area, including the rubrospinal and spinothalamic fibers, back to the level of the trapezoid body. Cat 140, in which the more rostral points were stimulated, gave the typical response from the brachium conjunctivum fibers and H_1 field when a level through the habenula and mammillary bodies (line *1*) was reached, although parts of the response were obtainable at other levels in the same region. In cat 141, the response came from the central tegmental fasciculus at level *4*, from the middle and ventral reticular areas at level *5*, from the middle and ventral reticular areas, including the rubrospinal and spinothalamic fibers at level *6*, from the ventral reticular area and spinothalamic fibers between levels *6* and *7* and from the ventral reticular area and rubrospinal tract at a level slightly caudal to line *7*. Parts of the brachium conjunctivum included in the reticular area yielded responses, but after the brachium rose dorsolaterally out of the reticular formation the response could no longer be obtained from it. Cat 142, which was explored in the more rostral region, from the level of the optic chiasm to the caudal part of the habenula, yielded no complete response, but gave parts of it from the H field and anterior brachium conjunctivum fibers. Cat 147 was also explored rostrally, but gave typical responses from the brachium conjunctivum (anterior capsule of the red nucleus) and the H field in the neighborhood of level *1*. Rostral to this point there was no complete response obtained, but rather a tendency to turn the head away from the side stimulated. Cat 151 was exceptionally reactive and gave the response over a wide area, first from the central tegmental fasciculus at a level between lines *4* and *5*, then from practically anywhere in the reticular areas, including the rubrospinal and spinothalamic tracts, the brachium conjunctivum and the descending limb of the brachium conjunctivum regions at this and succeeding levels back to just rostral to the trapezoid body. Caudal to this point it was elicited from the middle and ventral reticular areas, mostly lateral, as far caudal as the rostral part of the masticator nucleus.

Cat 169 gave the typical response from the central tegmental fasciculus region at the level of line *5* and from the middle and ventral medial reticular areas at the same level. Cat 170 gave the response from the middle medial reticular area dorsal to the red nucleus at level *3*, from the ventral reticular area lateral to the red nucleus at the same level, from the lateral part of the central tegmental fasciculus at level *5* and from the upper middle reticular area near this point. Cat 171 gave the response from the central tegmental fasciculus at a level between lines *2* and *3*, from the middle lateral reticular area at this level, from the central tegmental fascic-

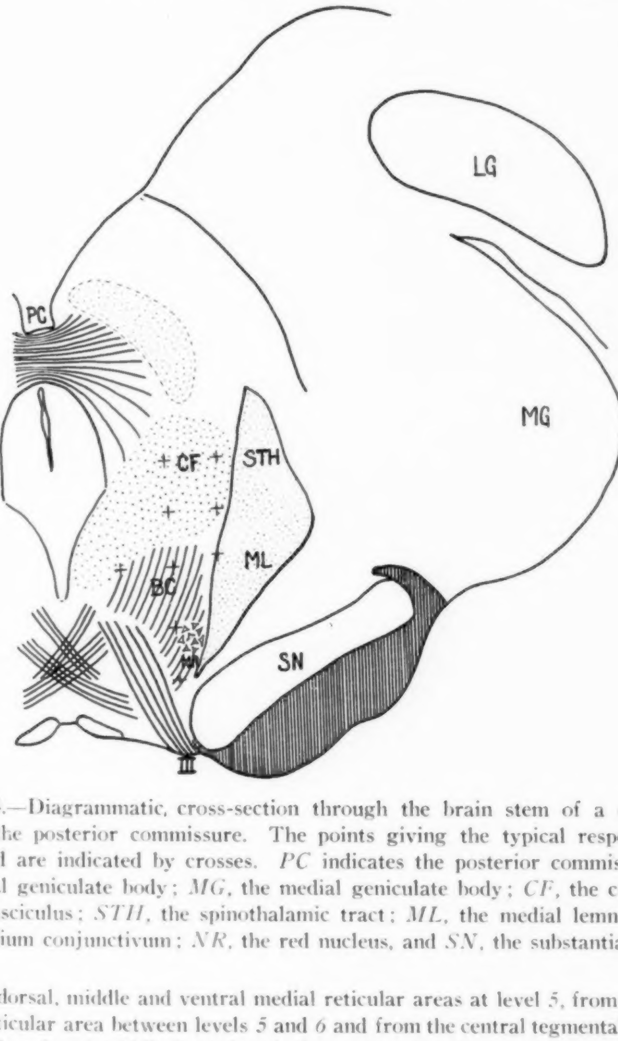

Fig. 4.—Diagrammatic, cross-section through the brain stem of a cat at the level of the posterior commissure. The points giving the typical response when stimulated are indicated by crosses. *PC* indicates the posterior commissure; *LG*, the lateral geniculate body; *MG*, the medial geniculate body; *CF*, the central tegmental fasciculus; *STH*, the spinothalamic tract; *ML*, the medial lemniscus; *BC*, the brachium conjunctivum; *NR*, the red nucleus, and *SN*, the substantia nigra.

ulus and dorsal, middle and ventral medial reticular areas at level *5*, from the dorsal lateral reticular area between levels *5* and *6* and from the central tegmental fasciculus and the dorsal and middle lateral reticular areas at level *6*. Cat 172 gave it from the dorsal lateral reticular area in the neighborhood of the lateral tegmental nucleus at line *3* and from the middle lateral reticular area at a level between lines *4* and *5*. Cat 173 gave the response from the ventral medial reticular area lateral to the red

nucleus at level *3*, from the dorsal and middle reticular areas at level *4* and from the dorsal, middle and ventral reticular areas between levels *4* and *5*. Cat 174 gave the response from the central tegmental fasciculus and dorsal reticular area at a level between lines *2* and *3* and from the same regions between levels *4* and *5*.

An attempt has been made to summarize these results pictorially in the diagrams (figs. 4 to 8), in which the areas that gave the tegmental response have been marked by crosses. It will be seen that the response can be elicited from most parts of the reticular formation of the midbrain and pons. It can be obtained from the regions occupied by the

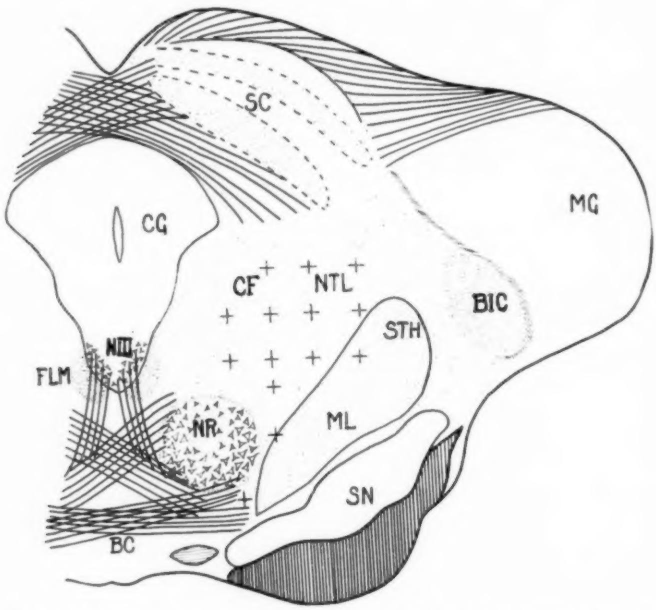

Fig. 5.—Diagrammatic cross-section through the brain stem of a cat at the level of the red nucleus. The points giving the typical response are indicated by crosses. *SC* indicates the superior colliculus; *MG*, the medial geniculate body; *CG*, the central gray; *CF*, the central tegmental fasciculus; *NTL*, the lateral tegmental nucleus; *BIC*, the brachium of the inferior colliculus; *STH*, the spinothalamic tract; *ML*, the medial lemniscus; *NR*, the red nucleus; *FLM*, the medial longitudinal fasciculus; *NIII*, the third nerve; *BC*, the brachium conjunctivum, and *SN*, the substantia nigra.

rubrospinal and spinothalamic tracts, parts of the medial lemniscus in conjunction with the contiguous reticular area, the central tegmental fasciculus and brachium conjunctivum, as well as from other parts of the tegmentum. Toward the caudal border of the pons it cannot be evoked from the dorsomedial part of the reticular formation (fig. 7), and at the rostral end of the medulla it apparently arises only from the lateral part between the trapezoid body and the central fasciculus and

from the region of the rubrospinal tract (fig. 8). We have not followed it beyond this point. Thiele [2] reported having traced it as far as the medulla by stimulating the cut surface of the brain stem.

That the response may be elicited by stimulation of the regions occupied by various tracts is undeniable. The central tegmental fasciculus,

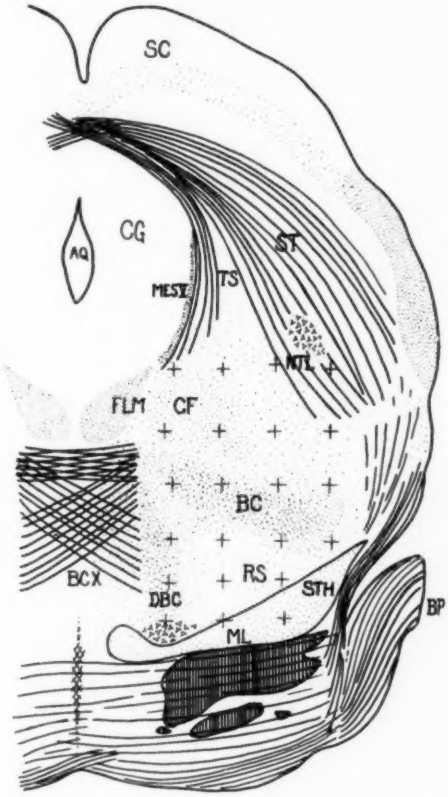

Fig. 6.—Diagrammatic cross-section through the brain stem of a cat at the level of the decussation of the brachium conjunctivum. The points giving the typical response when stimulated are indicated by crosses. *SC* indicates the superior colliculus; *CG*, the central gray; *AQ*, the aqueduct; *MESV*, the mesencephalic root of the fifth nerve; *TS*, the tectospinal fibers; *ST*, the spinotectal fibers; *NTL*, the lateral tegmental nucleus; *CF*, the central tegmental fasciculus; *BC*, the brachium conjunctivum; *BCX*, decussation of the brachium conjunctivum; *DBC*, the descending limb of the brachium conjunctivum; *RS*, the rubrospinal tract; *STH*, the spinothalamic tract; *ML*, the medial lemniscus; *BP*, the brachium pontis, and *FLM*, the medial longitudinal fasciculus.

the brachium conjunctivum, the descending limb of the latter and the rubrospinal and spinothalamic tracts have all given positive results. There is a question, however, whether these systems or the cells and

fibers of the reticular formation give the reaction. We are inclined to the latter view, since the tracts enumerated vary widely in their connections and function and some of them conduct impulses rostrad. There is a possibility that certain of these bundles include groups of descending fibers that may carry impulses concerned with the response for more or less short distances caudally. It is interesting to note that in our experiments the tegmental response could be obtained from the brachium conjunctivum within the reticular formation, but when stimulated in its more dorsal position, before it enters the reticular formation, it does not give the response. The ascending pathways, so far as the usual reaction is concerned, are, of course, eliminated from consideration by the fact that the same response has been elicited by stimulation of the cut surface of the mesencephalon in the experiments of previous investigators, in which only descending pathways could be considered.

The exaggerated typical response described earlier in the paper is a phenomenon difficult to account for. Its foci seem to be limited to the reticular formation caudal to the third nerve, including fibers of the rubrospinal and spinothalamic tracts. In cats 133, 134, 136, 137, 141, 151 and 173, in which it frequently appeared, it was elicited from the dorsolateral reticular area in two cases, while in the others it was usually obtained from middle and ventral regions of the reticular formation with the more lateral parts predominating, especially in the more caudal levels. It was at first thought to be due to the stage of anesthesia, but other cats and other regions failed to give it when very lightly anesthetized. There was also a possibility that it might be due to an augmenting of the movements by joint stimulation of the reticular area and the cerebral peduncle, but we were unable to show that such a response was elicited especially from in or near the peduncle. Moreover, it is not likely that stimulation of the ipsolateral peduncle would augment the response, since the reaction to pyramidal stimulation is contralateral. The evidences of spread to the sympathetic system might lead one to think of involvement of the hypothalamus, but in no case was this area found to give the response on direct stimulation. It is not improbable, however, that the influence of this area may at times be brought into the ordinary response, to a degree sufficient to cause its exaggeration, by stimulation of certain diffuse ascending pathways. Such impulses may be borne over the spinothalamic path, the central fasciculus or various fibers belonging to the trigeminal lemniscus. That this extreme type of response has not been described in decerebrate animals would tend to support this assumption.

Additional movements complicating the typical response obtained from the reticular formation were rather varied, even within individual

cases. There were various limb movements, among which an abduction of the contralateral fore limb predominated, and contractions of facial muscles were common, especially in highly responsive cats; among these the homolateral orbicularis oculi was most frequently active, with numerous contractions of the levator palpebrae. Movements of the eyes, chiefly contralateralward, were fairly common, while dilatation of

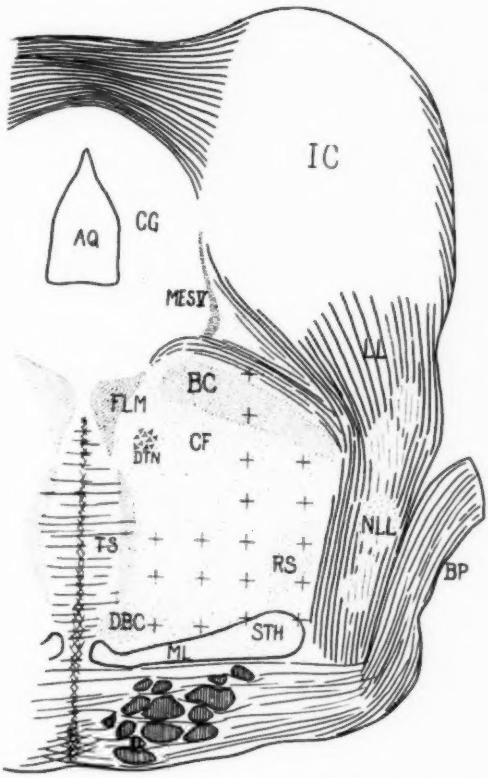

Fig. 7.—Diagrammatic cross-section through the brain stem of a cat at the level of the commissure of the inferior colliculus. The points giving the typical response when stimulated are indicated by crosses. *IC* indicates the inferior colliculus; *CG*, the central gray; *AQ*, the aqueduct; *MESV*, the mesencephalic root of the fifth nerve; *LL*, the lateral lemniscus; *NLL*, the nucleus of the lateral lemniscus; *BC*, the brachium conjunctivum; *CF*, the central tegmental fasciculus; *DTN*, the deep tegmental nucleus; *TS*, the tectospinal tract; *RS*, the rubrospinal tract; *STH*, the spinothalamic tract; *ML*, the medial lemniscus; *DBC*, the descending limb of the brachium conjunctivum; *BP*, the brachium pontis, and *FLM*, the medial longitudinal fasciculus.

the pupils was observed following stimulation practically everywhere in the reticular formation. Only once did we observe constriction of the pupils from stimulation of this area; this was from the dorsomedial part

near the level of the posterior commissure, not far from the oculomotor nerve. Cries were not infrequent and were often elicited when the area stimulated involved the spinothalamic tract. There was occasional spreading of the digits, particularly of the ipsolateral fore foot, and in two cats there was slight bristling of the hairs of the back. Caudally, near the level of the trapezoid body, stimulation caused contraction of the muscles of mastication; in this case the needle passed close to the motor nucleus of the fifth nerve.

Responses Elicited from Other Regions.—It may be well at this point to describe the effects of stimulation of a number of other regions explored in these experiments. The terminology used in this discussion is adapted after Rioch [8] and Papez.[9] In one case the extreme ventral part of the thalamus was explored as far forward as the preoptic area. In general this region appeared to be silent, although a slight retraction of the nictitating membranes resulted from stimulation of the medial preoptic and supra-optic areas. Other structures, including the anterior commissure, nucleus prethalamicus, fornix, olfacto-habenular fibers, nucleus tangentialis, medial part of the globus pallidus and olfactoseptal fibers, gave no response. The anterior inferior thalamic peduncle was unresponsive in the two cases in which it was stimulated. In the same two animals stimulation of the optic tract of the right side showed an inward rotation of the right eye and retraction of the nictitating membrane; in one of these constriction of the pupils was observed.

The nucleus subfascicularis, stimulated in three animals, was silent, while the ventral part of the nucleus ventralis medialis, aside from dilatation of the pupils, gave in a few instances indefinite movements of the fore limbs and swinging of the head, usually contralaterally. In the latter case there was some doubt as to whether fibers of the brachium conjunctivum were not stimulated. The ventral part of the nucleus ventralis of the thalamus was stimulated in four animals without definite results, aside from retraction of the nictitating membranes in two cases and dilatation of the pupils in three. Stimulation of the external medullary lamina (three cases) gave no consistent results, nor did that of the filiform nucleus or dorsal hypothalamic area. The periventricular gray of the hypothalamic region (three cases) gave dilatation of the pupils, a tendency to widen the palpebral fissures and slight move-

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8. Rioch, D. McK.: Studies on the Diencephalon of Carnivora: I. The Nuclear Configuration of the Thalamus, Epithalamus, and Hypothalamus of the Dog and Cat, J. Comp. Neurol. **49**:1, 1929; Studies on the Diencephalon of Carnivora: II. Certain Nuclear Configurations and Fiber Connections of the Subthalamus and Midbrain of the Dog and Cat, ibid. **49**:121, 1929.

9. Papez, J. W.: Comparative Neurology, New York, Thomas Y. Crowell Company, 1929.

ments of the eyes contralaterally. The nucleus hypothalamicus dorsomedialis (three cases) gave nothing consistent except dilatation of the pupils, nor did the nucleus hypothalamicus ventromedialis and the posterior hypothalamic region. The lateral hypothalamic area and medial forebrain bundle (four cases), aside from dilatation of the pupils, yielded contraction of the ipsolateral levator palpebrae and inward rotation of the ipsolateral eye; also in two cases the nictitating membrane was either retracted or elevated, with slight indefinite movements of the head.

The mammillary nuclei (three cases) gave no consistent results aside from occasional dilatation of the pupils. The zona incerta was stimulated in four cats, although it was sometimes evident that fibers of

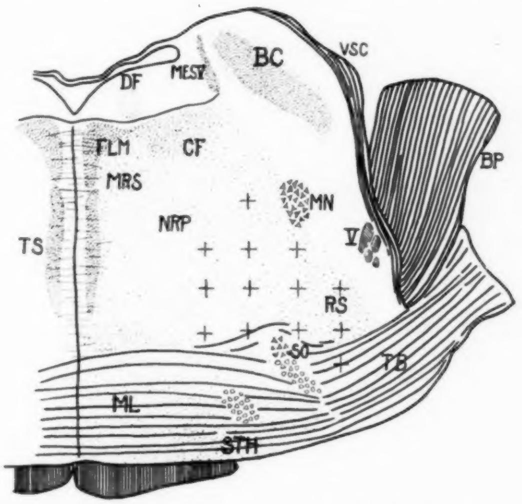

Fig. 8.—Diagrammatic cross-section through the brain stem of a cat at the level of the trapezoid body. The points giving the typical response are indicated by crosses. *BC* indicates the brachium conjunctivum; *MESV*, the mesencephalic root of the fifth nerve; *DF*, the dorsal longitudinal fasciculus; *VSC*, the ventral spinocerebellar tract; *BP*, the brachium pontis; *CF*, the central tegmental fasciculus; *MRS*, the medial reticulospinal tract; *NRP*, the reticular nucleus of the pons; *TS*, the tectospinal tract; *MN*, the masticator nucleus; *RS*, the rubrospinal tract; *SO*, the superior olive; *TB*, the trapezoid body; *ML*, the medial lemniscus; *STH*, the spinothalamic tract, and *FLM*, the medial longitudinal fasciculus.

the H_1 field or brachium conjunctivum were also stimulated. In the latter cases there was a contralateral turning of the head. The zona incerta alone gave rotation of the eyes contralaterally, with dilatation of the pupils. Stimulation of the H_2 field yielded practically the same results, with occasional retraction of the nictitating membranes.

The fibers of the anterior portion of the brachium conjunctivum or the anterior capsule of the red nucleus in the region of the H_1 field about the level of line *1* (fig. 3) are in the most rostral area to give what approaches the typical response. The most rostral fibers usually gave a contralateral head turning, as was also observed by Sachs,[10] but as one worked caudally the complete typical response with an ipsolateral head turning usually appeared near the caudal border of the subthalamus. More anteriorly there are also occasional retraction of the nictitating membrane and contralateral rotation of one or both eyes. The nucleus subthalamicus (five cases), aside from occasional dilatation of the pupils and contralateral head turning, yielded chiefly contraction of the ipsolateral levator palpebrae, a clonic tremor of wide extent or slower repeated flexion of the contralateral fore limb, which was perhaps due to pyramidal influences and contralateral rotation of one or both eyes.

The central tegmental fasciculus, stimulated in most of the experiments, usually gave typical responses, except at its more rostral levels, where contralateral movements of the head were common, and at the more caudal levels of the explored areas (pons and medulla). Occasional other responses, usually accompanying a typical one, included contractions of the orbicularis oculi muscles, slight cries and flexion of one or both hind limbs.

Spinotectal fibers were also stimulated in most of the experiments, often along with parts of the dorsal reticular area, in which case typical or partially typical responses resulted. When these fibers were stimulated after they had left the tegmentum they gave nothing of note, except for pupillary dilatations and occasional contralateral movements of the head (nine cases) or eyes. The brachium conjunctivum, caudal to the red nucleus, passes through the responsive reticular area, and when it is stimulated in this region the typical response with flexion of one or both hind limbs and dilatation of the pupils resulted. However, it was observed in cases in which exploration extended far caudad, that when the more caudal extrareticular part of the brachium was stimulated no response resulted.

The fibers of the spinothalamic tract were often involved with areas of the reticular formation, which produced typical responses on stimulation. Only occasionally were such responses slightly atypical or partial. Aside from a consistent dilatation of the pupils, the most interesting feature of responses from this area was the frequency with which a peculiar and characteristic cry was elicited—no less than ten cats of the group in which the loci of the stimuli were verified by microscopic

10. Sachs, E.: On the Structure and Functional Relations of the Optic Thalamus, Brain **32**:95, 1909.

examination showed this. It must be remembered, however, that other diverse regions in the reticular formation also produced efforts at vocalization which sometimes were manifest only as characteristic variations in respiratory movements. A number of the animals the spinothalamic tracts of which were stimulated also showed changes in respiration ranging from rapid, shallow breathing during the period of stimulation to a complete cessation of this activity. Other responses, such as spasms of the facial musculature, erection of hairs and spreading of the digits, were rather rarely obtained from stimulating the spinothalamic tracts.

Stimulation of the medial lemniscus region (ten animals) was also complicated by the presence of reticular fibers in this area. A number of partially typical responses came from this region, and rather frequently a turning of the head resulted. Other movements, except dilatation of the pupils, were infrequent. The lateral lemniscus was reached in only two cats and showed nothing definite, nor did the brachium of the inferior colliculus or the inferior colliculus itself give us positive results with stimuli of the low intensity used in these experiments.

In cases in which the tip of the electrode rested in the locality of the substantia nigra it was often difficult to determine whether or not part of the ventral reticular area, medial lemniscus, spinothalamic tract or the cerebral peduncle were also stimulated. That the peduncle was often involved is indicated by the frequency of flexions of the contralateral limbs, often of a quick type with absence of after-discharge. True typical responses were not produced, and the number of times the head was moved contralaterally equalled the number of ipsolateral turnings. Contralateral eye movements occasionally were observed.

The cerebral peduncles, stimulated at various levels, gave responses in eight cats. The stimulus used in our experiments was weak and probably in many instances below the threshold for the peduncle, and the comparative rarity of pyramidal responses is ascribed to this fact. The eight responsive cats gave us no instance of our typical response, the most constant feature being quick flexion of the contralateral limbs. Occasionally a generalized muscular contraction resulted, affecting the muscles of the neck and back particularly. Contralateral movements of the head were frequent, ipsolateral occasional, and movements of one or both eyes were observed a few times. In one cat, in which the peduncle fibers were stimulated well forward at a level through the rostral part of the habenula and mammillary bodies, ventromedially to the globus pallidus, responses closely resembling swallowing and sucking were observed.

The rubrospinal tract, as shown in table 2, which summarizes responses from this region, gives many typical or partially typical

responses. This could not be due to stimulation of the rubrospinal fibers themselves, because section of these fibers in the decussation of Forel does not impair the response obtained by stimulation of the cut surface of the mesencephalon (Brown,[3] Környey,[4] Hinsey, Ranson and Dixon[1]). However, the part of the reticular formation which gives the response at the level of the trapezoid body is in fairly close proximity to the rubrospinal pathway. The table does not indicate the fact, but a number of the limb responses elicited from the region of this tract are clonic in nature, nor does it show that the facial muscle brought into play here is always the ipsolateral orbicularis oculi.

COMMENT

The response obtained by stimulating the mesencephalic tegmentum with an electrode inserted into an otherwise intact brain is essentially the same as that elicited when the electrode is applied to the cut surface of the tegmentum in a decerebrate preparation. However, in the latter type of experiment the neural balance favors the appearance of extensor reactions, hence extension of the contralateral fore limb is of greater amplitude and more regularly obtained than in animals with intact forebrains.

In cats and monkeys the response is practically identical. It conforms to a definite, stereotyped pattern, and the same movements may be repeated with little variation as often as the stimulus is applied. It is difficult to think of any useful purpose which the association of limb movements with a lateral curving of the neck and trunk could subserve or how this pattern could enter as an integral part into the normal activity of a mammal. The curving of the spine, however, associated with the flexion of one fore limb and the extension of the other, suggests somewhat the locomotor efforts of Amblystoma larvae when removed from the water, and it may possibly be that we are dealing here with an instance of the integration of trunk and body movements related to that described for Amblystoma by Coghill.[11] The jump down the phylogenetic ladder from the cat to the salamander seems a long one, but in this connection it is interesting to note that Windle and Griffin[12] have found that the earliest movement that can be observed in kitten embryos is a bending of the neck similar to that which forms an integral part of the tegmental response in the adult cat. In somewhat older embryos a lateralward bending of the neck and trunk is associated with flexion and extension of the fore limbs, the movements of the latter members being closely integrated with those of the head and neck.

11. Coghill, G. E.: Anatomy and the Problem of Behaviour, London, Cambridge University Press, 1929.

12. Windle, W. F., and Griffin, A. M.: Observations on Embryonic and Fetal Movements of the Cat, J. Comp. Neurol. **52**:149, 1931.

These concurring facts and consideration of the well known primitive function of the midbrain as a primary motor center lead one to consider seriously the question: Does the mesencephalic tegmentum retain in its adult arrangement a phylogenetically old pattern, from which, by direct stimulation, an ancient type of reaction not normally evoked in post-natal life may be elicited?

The response can be obtained from most parts of the reticular formation of the mesencephalon and pons. It can also be elicited from the subthalamus in the region of the anterior part of the capsule of the red nucleus and from the reticular formation of the medulla near the rubrospinal tract at the level of the trapezoid body. It is not specifically related to the red nucleus; indeed it appears to be difficult, if not impossible, to obtain the reaction by stimulation of the red nucleus in animals with intact forebrains. It is most easily and regularly obtained from the tegmentum dorsolateral to the red nucleus and from the region occupied by the central tegmental fasciculus at the more rostral levels. All of the descending fibers known to arise from the cells of the red nucleus cross in the decussation of Forel, and any consideration of these as concerned in the response is precluded by the fact that the response is not impaired by division of these fibers in their decussation by a medial section of the midbrain. However, the region occupied by the rubrospinal fibers from the opposite side gives the response in typical form through the pons and into the rostral part of the medulla. It is not improbable that that part of the reticular formation which gives the response at the level of the trapezoid body contains fibers, not rubral in origin, that carry impulses responsible for the typical tegmental response as elicited by stimulation of the mesencephalon, which may lie in relatively close relationship topographically with the rubrospinal tracts. It has not been possible to attribute the reaction to any special group of cells or to any definite fiber tracts. The mechanism seems to include the reticular formation as a whole and is not to be differentiated into specific nuclei or tracts. This is what might be expected if the response represents, as has been suggested, a phylogenetically old reaction pattern which has, for normal intent and purposes, been discarded in the progress of development.

The region Graham Brown [3] designated as the "red nucleus area" in his diagram is within the field from which we obtained many of our best reactions, but it lies for the most part dorsal and lateral to the red nucleus. Within this area is located the central tegmental fasciculus. As has already been mentioned, we have not been able to elicit the reaction from the red nucleus in cats with intact brains except in one instance from the extreme rostral end near the field of Forel and in six instances from the reticular area at its lateral border. It is possible

that, when this nucleus is stimulated in the intact cat, impulses ascending to the forebrain may evoke inhibitory discharges that prevent the response. However, it must be admitted that the number of times that the center of the red nucleus was stimulated in these experiments (three cats) is not sufficient to furnish adequate grounds for the assumption that the red nucleus does not yield the response under these conditions. The scarcity of cases of direct stimulation of the red nucleus in this series of experiments is due to the fact that it was early observed that when the needle was placed 1 mm. to the side of the midline no responses or else left head turnings resulted. Therefore, in the majority of the subsequent experiments the needle was not brought close enough to the midline to insure hitting the red nucleus. Additional work must be done to settle this question.

In no instance were tegmental responses obtained from stimulation of the substantia nigra; in fact, so far as we could determine, this region was silent. Such responses of various types as were obtained near its dorsal border could more easily be explained as due to the involvement of the tegmentum, and those from points near its ventrolateral border as due to involvement of the pyramids. These observations coincide with those of Hinsey, Ranson and Dixon,[1] who found that stimulation of the tegmentum still evoked the response after complete removal of the substantia nigra.

It must be pointed out that in the consideration of the responses evoked from the brain stem anterior to the mesencephalon, or even from certain parts of the mesencephalon, and of the areas which apparently remain silent on stimulation, one must remember that the stimuli applied were very weak. A minimal stimulus suitable for evoking the tegmental response was determined early in our experiments, and all explorations were carried out on this basis. No doubt, additional information can be obtained on these points by the use of stimuli of sufficient strength to pass higher thresholds. One should note, also, that only responses of a "visible" or external nature have been described and discussed in this communication.

SUMMARY

Faradic stimulation of the mesencephalic tegmentum through needle electrodes in cats with intact brains evoked a response similar to that elicited by its stimulation on the cut surface of the brain stem in decerebrate animals. This response consists essentially of a curving of the head, neck and trunk toward the side stimulated, flexion of the ipsolateral fore limb and extension of the contralateral fore limb, with varying movements of the hind limbs. In certain cases parts of this response may be elicited; in others, a variety of divergent reactions may be added to it. Occasionally it may be greatly exaggerated.

This response pattern may be obtained from the caudal part of the subthalamus in the region of the anterior capsule of the red nucleus, from the reticular formation of the tegmentum, dorsal and lateral to the red nucleus, including the central tegmental fasciculus, and caudal to the red nucleus from almost anywhere in the reticular formation back to the caudal part of the pons, where its foci seem to shift laterally until at the level of the trapezoid body they appear to lie ventrally and laterally in the neighborhood of the rubrospinal tract. The response is not specifically related to the red nucleus. In fact, considerable difficulty was experienced in obtaining it from this nucleus in cats with intact forebrains.

The response may be elicited by stimulation of the regions in the tegmentum occupied by various tracts such as the central tegmental fasciculus, brachium conjunctivum and rubrospinal and spinothalamic tracts, but there is no evidence that these take any special part in it. It seems more probable that it should be attributed to cells and fibers of the reticular formation through which these tracts run.

A large area of the brain stem was explored in these experiments rostrally through the hypothalamus, subthalamus and extreme ventral part of the thalamus as far as the preoptic area. This area, with the exception of the field of Forel, was for the most part silent with the weak stimuli employed, but sometimes eye movements and sympathetic responses, and occasionally a turning of the head away from the side stimulated, were obtained.

The response was never obtained from stimulation of the substantia nigra, and it has been shown that it can be obtained from the mesencephalic tegmentum after the substantia nigra has been removed.

RELATION OF THE CEREBRUM TO THE CEREBELLUM

I. CEREBELLAR TREMOR IN THE CAT AND ITS ABSENCE AFTER REMOVAL OF THE CEREBRAL HEMISPHERES *

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The present paper and those that follow in this series embody the results of a systematic attempt to study the consequences of removal of related portions of the cerebellum and cerebral hemispheres in a large series of mammals, including monkeys and the higher apes. The basis of the investigation is the familiar fact that the neocerebellum has developed in evolutionary history *pari passu* with the growth of the cerebrum, which bespeaks an intimate functional association between the two [1] (Rossi [2]).

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Dr. Rioch was a National Research Council Medical Fellow at the time this work was done.

Read at a Joint Meeting of the Section on Neurology and Psychiatry of the New York Academy of Medicine and the New York Neurological Society, Nov. 10, 1931.

* That is, in a "chronic" decerebellated thalamic preparation.

1. We do not propose to deal here with the history of experimental work on the cerebellum, as this has already been done by one of us (Fulton, J. F.: Muscular Contraction and the Reflex Control of Movement, Baltimore, Williams & Wilkins Company, 1926, chap. XX, and adequately by: (*a*) L. Luciani (Il cervelletto: Nuovi studi di fisiologia normale e patologica, Firenze, successori Le Monnier, 1891; ibid., Das Kleinhirn, translated into German by M. O. Fraenkel, Leipzig, E. Bezold, 1893; Human Physiology, translated from the German by F. A. Welby, New York, The Macmillan Company, 1915, vol. 3), (*b*) C. S. Sherrington (The Parts of the Brain Below the Cerebral Cortex, viz., Medulla Oblongata, Pons, Cerebellum, Corpora Quadrigemina, and Region of Thalamus, in Sharpey-Schafer, E. A.: Text-Book of Physiology, Edinburgh, Young J. Pentland, 1900, vol. 2), (*c*) G. van Rijnberk (Idées actuelles et derniers travaux concernant les fonctions du cervelet, Arch. néerl. de physiol. **10**:155, 1925; Les dernières recherches relative à la question de la localisation dans le cervelet: Anatomie,

At the beginning of our work it was thought essential to analyze the results of complete decerebellation and of complete decortication in cats, dogs and monkeys; later, we undertook to observe the effects of localized lesions of the cerebellum and cerebral hemispheres. We believe that the study has shed considerable light on some phases of the functional activity of the cerebellum, and we propose now to record them seriatim.

Our first observations relate to the genesis of cerebellar tremor in the cat and to its disappearance after removal of the cerebral hemispheres.

CEREBELLAR TREMOR

The outstanding features of the disturbance following removal or injury of the cerebellum are well known in both animals and human beings. The most striking symptom is a profound incoordination of the skeletal musculature, characterized by coarse intention tremor which increases as voluntary effort is augmented. First recognized by Flourens [3] in 1824 all investigators now accept this symptom as pathognomonic of a cerebellar lesion, and we believe that it is the basis of the chief signs and symptoms of pure "cerebellar" deficit. The essential disturbance has been variously termed "astasia," [1a] "asynergia" [1f] or simply "cerebellar tremor." Many explanations of the phenomenon have been offered; some, for example, hold that the locomotor defect is due to the "hypotonia" that is thought to accompany cerebellar lesions; i. e., the joints are loose, and, once a movement is started, the extremity tends to overshoot its mark because of slackness of the opposing muscles.[4] Dusser de Barenne [1e] was the first to prove definitely that this explanation could not hold, since when the cerebellum was carefully removed, hypotonia, in fact, did not occur. It was evident, therefore, that some other explanation must be sought.

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physiologie, clinique, ibid. **10**:183, 1925), (*d*) F. R. Miller (The Physiology of the Cerebellum, Physiol. Rev. **6**:124, 1926), (*e*) J. G. Dusser de Barenne (Die Funktionen des Kleinhirns: Physiologie und allgemeine Pathologie, in Alexander, Gustav, and Marburg, Otto: Handbuch der Neurologie des Ohres, Berlin, Urban & Schwarzenberg, 1923, vol. 1, p. 589), (*f*) T. H. Weisenburg (Cerebellar Localization and its Symptomatology, Brain **50**:357, 1927), (*g*) G. G. J. Rademaker (Das Stehen, Berlin, Julius Springer, 1931) and many others. Historical discussions are also included in the two recent symposiums on the cerebellum, one published in Brain (**50**:275, 1927) and the other as a separate volume by the Association for Research in Nervous and Mental Disease (Baltimore, Williams & Wilkins Company, 1929).

2. Rossi, G.: Sue rapporti funzionali del cervelletto con la zona motrice della corteccia cerebrale, Arch. di fisiol. **11**:258, 1913.

3. Flourens, M. J. P.: Récherches expérimentales sur les propriétés et les fonctions du système nerveux dans les animaux vertébrés, Paris, Crevot, 1824.

4. Walshe, F. M. R.: On Disorders of Movement Resulting from Loss of Postural Tone, with Special Reference to Cerebellar Ataxy, Brain **44**:539, 1921.

Before going into the question of hypotonia it seemed to us desirable to obtain accurate information concerning the onset and development of tremor immediately after the cerebellum had been removed, for we thought that this might offer a clue to its nature. It is obvious, at the outset, that tremor could not be due to the cerebellum itself, since the cerebellum is removed. This might seem to be stressing the obvious, but it is too often forgotten in clinical discussions of cerebellar dysfunction (Walshe [5]). The ataxia, as Walshe [5] has emphasized, is seen only in voluntary movements and is not observed, for example, in a spinal animal (dog or cat). The question therefore arises at once: What part of the nervous system is responsible for the appearance of tremor? Can we, by removal of any portion of the brain, do away with tremor and ataxia once it has appeared? It was this feature of the problem that had not been experimentally approached, as far as we were aware, by other workers. Rademaker's [6] brilliant study of a thalamic dog that survived for thirty-eight days after decerebellation did not allow him to study the point, since the cerebral hemispheres had been removed before he extirpated the cerebellum.

The removal of the cerebellum from a cat is a relatively simple operation, provided it is carried out under one of the barbituric acid anesthetics.[7] Under ether the hazards are increased many-fold, the convalescence is stormy, and reactionary hemorrhage into the posterior fossa is almost inevitable. The details of the surgical approach to the cat's cerebellum are described elsewhere.[8] It is often possible to remove the cerebellum cleanly and completely in one piece, without the loss of more than from 1 to 2 cc. of blood and without changing the animal's rate of respiration.

We have successfully decerebellated thirty-six cats, and our experience with this group of animals has served to emphasize the following facts: During the first two or three days after operation, the animal has marked spasms of opisthotonos. There is no tremor of the skeletal

5. Walshe, F. M. R.: The Significance of the Voluntary Element in the Genesis of Cerebellar Ataxy, Brain **50**:377, 1927.

6. Rademaker, G. G. J., and Winkler, C.: Annotations on the Physiology and the Anatomy of a Dog, Living 38 Days, Without Both Hemispheres of the Cerebrum and Without the Cerebellum, Verhandl. v. k. Akad. v. Wetensch. **31**:332, 1928.

7. Fulton, J. F.: Lidell, E. G. T., and Rioch, D. McK.: "Dial" as a Surgical Anaesthetic for Neurological Operations: With Observations on the Nature of Its Action, J. Pharmacol. & Exper. Therap. **40**:423, 1930. Fulton, J. F., and Keller, A. D.: Observations on the Response of the Same Chimpanzee to Dial, Amytal, and Nembutal, Used as Surgical Anaesthetics, Surg., Gynec. & Obst. **54**:764, 1932.

8. Fulton, J. F.; Liddell, E. G. T., and Rioch, D. McK.: The Surgical Approach to the Cerebellum and Cerebral Hemispheres of the Cat, Monkey and Higher Apes, in preparation.

musculature until voluntary movements begin to occur. During the first two or three days the animal ordinarily lies on its side quite motionless apart from seizures of opisthotonos; on the third or fourth day, it is likely to begin holding its head in the horizontal posture, and at that time a coarse tremor of head and neck becomes apparent. Tremor of the extremities ordinarily does not appear until the animal makes active attempts to walk, usually on the seventh or eighth day. We are therefore inclined to attach significance to the fact that tremor as such does not come on until the animal begins voluntarily to use its extremities. Involuntary spasms are unassociated with tremor. The observations are entirely in harmony with previous studies on the cerebellum,[9] and, though not essentially new, the slow development of "voluntary" tremor is not commonly mentioned. We believe that it is a fact deserving of special emphasis. The course pursued in the cat after decerebellation is well illustrated by the following example:

Experiment 1.—*Complete removal of the cerebellum; opisthotonos for three days; tremor of head on fourth day, generalized tremor and ataxia on eighth day; walking regained.*

A well nourished female tiger cat, not more than a year old, weighing 2,350 Gm., was carefully observed for several days. She proved playful, gentle, well coordinated and house-broken.

Operation (Feb. 22, 1930).—Under diallylbarbituric acid anesthesia (intraperitoneal), the cerebellum was exposed by separating the muscles of the neck at the midline. The posterior vermis was elevated, and the peduncles were cut through, first on one side and then on the other, by means of a small curved knife. The cerebellum was broken in the process of extracting it from the posterior fossa, but the extirpation was virtually complete. The hemorrhage was fairly brisk at first, but was readily controlled. The respiration and circulation were little if at all disturbed by the procedure. The wound was closed in layers with discontinuous silk sutures.

Postoperative Observations.—First Day: The cat was quiet early in the morning, with fairly marked opisthotonos and retraction of the head. By 11:30 p. m., she had almost completely recovered from the anesthesia, and the opisthotonoid seizures had increased markedly in severity and frequency. There was no voluntary movement, but one observed a fairly marked resistance. Lateral nystagmus was occasionally seen.

Second Day: All effects of the anesthetic had disappeared, and the animal lay on its side in the cage, attempting to hold its head in the horizontal position, and as yet there was no sign of tremor or ataxia in any of its movements. Any sudden stimulation, such as patting the head or making a sound near it, provoked a marked seizure of opisthotonos and extension of the fore limbs and marked retraction of the head. The animal did not appear to be in any discomfort during these seizures. It drank a large quantity of water and took solid food. Respiration was still regular, and the mouth was clean.

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9. (*a*) Magnus, R.: Körperstellung, Berlin, Julius Springer, 1924. (*b*) Luciani (footnote 1 *a*). (*c*) Miller (footnote 1 *d*). (*d*) Dusser de Barenne (footnote 1 *c*). (*e*) Rademaker (footnote 1 *g*).

Third Day: The animal was sitting more or less horizontally in its cage, and there was practically no tremor of the head when lapping water from a dish. Voluntary movements, however, were still restricted, and the animal sat for long periods of time immobile, as if voluntarily attempting to prevent motion. No asymmetry could be detected in the resting posture, and all four extremities were markedly hypertonic—to an extent, in fact, that precluded testing of the positive supporting reaction. Opisthotonoid seizures still continued, but were definitely less intense.

Fourth Day: The animal was sitting up in the cage, holding the head in a horizontal posture and moving little. For the first time one noted a marked oscillating tremor whenever it attempted to stretch the head forward to drink or to take solid food. For the most part, it seemed to avoid voluntary movement, and there were no violent oscillating movements of the whole body such as one saw at a later stage. The hypertonia of the extremities was less marked, and the opisthotonoid seizures had diminished in intensity. The positive supporting reactions were vigorous and readily elicited on a slight contact with the pads of the feet. The knee jerks were present and equal, but sluggish.

Fifth Day: The tremor had increased very little; the animal was quiet, and fed well. Opisthotonoid seizures were still present.

Sixth Day: Infrequent opisthotonoid seizures were present, but there was possibly a slight increase in the oscillating movements of the head. The general condition was entirely satisfactory.

Eighth Day: The animal attempted for the first time to get onto its feet and succeeded in taking several steps forward before toppling over. The tremors of all extremities were much more marked than at any time since the operation, and had begun to appear in the extremities as well as in the movements of the head.

Ninth Day: The oscillating tremor was fully developed. By this time the tremor and all movements had become as marked as in any of the other thirty animals in the series. The animal was making excellent progress in locomotion and had begun to attempt to follow a string like a playful kitten, but she frequently toppled over.

Tenth Day: Progress in walking continued, and the oscillating tremor was still increasing. The animal also began at this time to show, in striking form, the symptom of retropulsion. When placed on its feet suddenly, it often began running rapidly backward and at times turned a backward somersault. The seizures of retropulsion usually came suddenly, and the animal seemed unable to control them. Between such seizures it was playful and gentle and progressed rapidly toward any object that moved. It was much interested in its surroundings and showed no mental impairment. No change in the voice was detected.

Eleventh Day: The general condition was the same. Righting reflexes were present; crossed reflexes could be elicited on either side of the body, and a strong positive supporting reaction could be obtained on gently pressing the soles of any one of the four feet.

Fourteenth Day: The only change was an improvement in walking; encouragement had been given as frequently as possible by taking the animal from the cage and making it progress toward food. Usually after four or five steps, however, it fell over, and in doing so executed wildly ataxic movements of all extremities. Occasional attacks of retropulsion continued, but opisthotonos had ceased completely.

Twenty-First Day: Voluntary activity was still increasing and continued to be associated with the wildest ataxia, as marked as, if not more marked than, in any other animal in the series, probably because the cat was making many more spontaneous attempts toward voluntary movement. The degree of ataxia varied with the amount of activity. After it had been following a string for a time, it usually became utterly incapable of standing on its feet for some minutes.

Thirtieth Day: Walking was still improving somewhat; the animal showed a high stepping gait and proceeded on an extremely broad base, with ataxia undiminished. The animal's ocular movements were frequently examined during the preceding two weeks, and no trace of nystagmus was seen.

Thirty-Fifth Day: The animal had reached an essentially steady state, being alert, active and playful. Photographs were taken, showing the scratch reflex, which was executed without ataxia (fig. 1), and the incoordinated walking movements. On this day the animal attempted to catch a bird in a bush adjacent to the place where the photographs were made.

Subsequent Course.—Following a secondary operation, the animal caught the wound on the cage door, opened and infected it. At autopsy, which was carried out forty-two days after the cerebellum had been removed, the posterior fossa was

Fig. 1 (experiment 1).—Scratch reflex in a decerebellate cat, obtained thirty-five days after removal of the cerebellum. The scratching movement was executed without evidence of tremor.

well covered with a layer of false dura, and the cerebellum had been completely removed apart from a very small tag, which still remained attached to the left middle peduncle.

We have many other instances in our series closely parallel to this, but few in which the oscillating tremor was as marked and none in which the animal recovered its powers of locomotion to so great an extent. We have carried out cerebellar extirpation also in four dogs and have observed roughly the same sequence of events; we are able entirely to confirm Rademaker's [1g] observation on postural reactions in decerebellate dogs. The ataxia as such does not appear for three or four days and increases in intensity during the first ten days. Dogs, however, ultimately make much more strenuous efforts to execute voluntary movements than do cats, as Rademaker [1g] previously emphasized.

The problem of the relation of hypotonia to hypertonia following cerebellar extirpations may well be considered here. Our experience

agrees entirely with that of Dusser de Barenne [1e] and Rademaker,[1g] who found that following complete removal of the cerebellum, hypotonia is never seen unless the medullary centers have been injured. In the following experiment the medullary centers were injured on one side, with the result that the animal had an asymmetric posture and marked hypotonia on the right side.

Experiment 2.—*Complete removal of cerebellum, injury of right side of medulla: asymmetric posture; hypotonia of right extremities.*

Operation (*Feb. 9, 1930*).—A black male cat, weighing 2,500 Gm., was operated on under intraperitoneal diallylbarbituric acid anesthesia; the entire cerebellum was removed, but in cutting through the peduncles on the right side the knife was

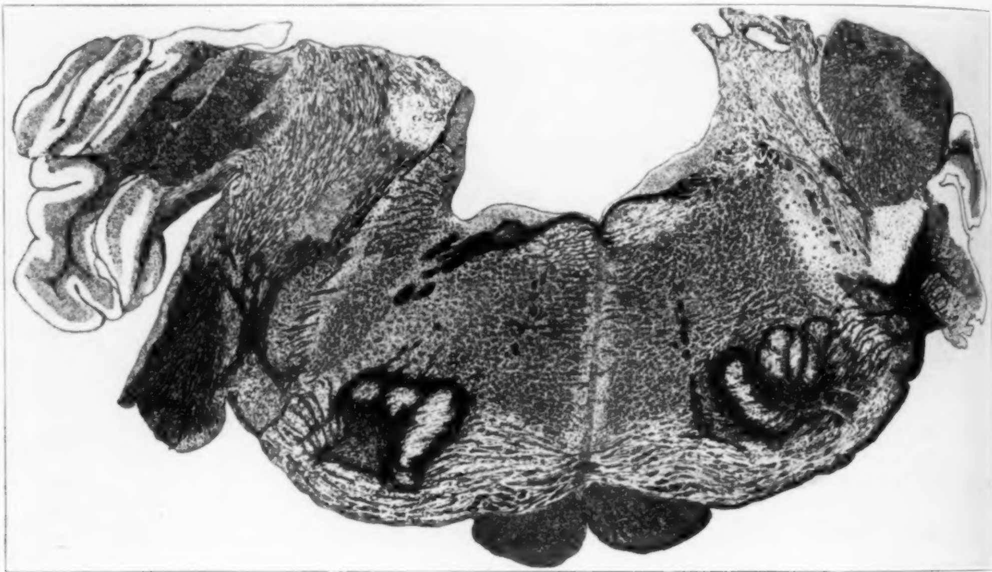

Fig. 2 (experiment 2).—A section through the medulla oblongata at the level of the vestibular nuclei, showing virtually complete degeneration of the right Bechterew's and Deiters' nuclei. Stained with iron hematoxylin. (See microscopic report.)

allowed to scrape too close to the medulla and injured it in the region of the vestibular nucleus. This did not affect respiration, and the animal made a prompt recovery.

Postoperative Observations.—Opisthotonoid seizures were present during the first week, gradually becoming less intense. Asymmetry of posture was noted directly after the operation, the animal's head being rotated clockwise when the body was held in the horizontal plane. This became more marked during the first week, at the end of which time it was also noted that the right extremities were hypotonic and that there was no positive supporting reaction in the right hind leg. The animal lay constantly on its left side. The postural asymmetry and the hypotonia of the right extremities showed some improvement at the end of four weeks.

At autopsy, thirty-four days after the removal of the cerebellum, it was found that the cerebellum had been completely removed and that a fairly large scar was present in the medulla, corresponding to the region of the right vestibular nuclei. Serial sections through the area, stained with iron hematoxylin, indicated that the vestibular nuclei had been extensively injured (fig. 2).

Microscopic Report.—On the left, a small portion of cerebellar cortex was still intact and connected with fibers of the brachium pontis. It was apparently the ventromedial part of the lateral lobe. The dorsal third of Bechterew's nucleus showed degeneration, but the other vestibular nuclei, including Deiters', were intact. On the right, there was no cerebellar cortical tissue in connection with the stumps of the peduncles. Bechterew's nucleus was entirely degenerated, as was also, apparently, Deiters' and the dorsolateral portion of Schwalbe's. The restiform body could not be definitely identified on the right. The right half of the medulla was considerably smaller than the left, probably due to the degenerations noted (fig. 2).

This observation agrees with our previous conclusion [10] that isolated injury to the vestibular nuclei causes hypotonia on the side of the lesion in an otherwise normal cat.

These preliminary studies are in harmony with the clinical suspicion (Walshe) that the ataxia following cerebellar extirpation results from activity of the centers controlling voluntary movement. We have therefore attempted in the cat to remove both cerebral hemispheres in two stages after cerebellar tremor has become well established. The experiment thus involves three successive operations, and success depends largely on attention to details of nursing care. Thus far, five animals have survived the triple operation for periods of five, six, thirteen, fourteen and sixteen days, respectively. In each case death was due to some fault in nursing care, and we are confident that we shall ultimately be able to keep decerebellate thalamic preparations alive for an indefinite period.

THE SEMIDECORTICATE DECEREBELLATE PREPARATION

On removing the hemisphere from a decerebellate preparation, the extremities on the opposite side become conspicuously hypertonic for the first three or four days, during which very few spontaneous movements are seen, and the condition is in every way similar to the state of muscles in decerebrate rigidity. Later, associated movements begin to appear, but these are not accompanied by tremor. When the animal is placed on its back, the rigidity of the hemiplegic extremities becomes greatly augmented. Our observations on this point are essentially in harmony with those of Rademaker,[11] who has made similar observations

10. Fulton, J. F.; Liddell, E. G. T., and Rioch, D. McK.: The Influence of Unilateral Destruction of the Vestibular Nuclei upon Posture and the Knee Jerk, Brain **53**:327, 1930.

11. Rademaker, G. G. J.: Expériences sur la physiologie du cervelet, Rev. neurol. **1**:22, 1930; footnote 1 *g*.

on dogs. The following experiment on a semidecorticate decerebellate cat will serve to illustrate these and a number of other points.

Experiment 3.—*Removal of cerebellum: ataxia and tremor. Removal of left cerebral hemisphere: right-sided "decerebrate rigidity." Removal of right hemisphere.*

A well groomed, female, tortoise-shell cat, weighing 3,000 Gm., in good physical condition, was studied for several weeks prior to operation, and proved playful, friendly and entirely normal in all locomotor movements.

First Operation (Oct. 28, 1929).—Complete removal of the cerebellum. Under diallylbarbituric acid anesthesia (intraperitoneally), the posterior cerebellum was exposed, and the peduncles were cut through on both sides after elevating the posterior vermis. The cerebellum was removed completely in one piece and preserved (fig. 3). The hemorrhage was trifling, and before closure one could see clear cerebrospinal fluid emerging from the aqueduct of Sylvius. The peduncles were cut through cleanly, and the medulla was uninjured.

Postoperative Observations.—The postoperative course in this animal was similar to that in experiment 1. Opisthotonoid seizures continued for nearly two weeks, and ataxia of the head and extremities began to be evident after the fourth or fifth days, increasing considerably when the animal began to walk (fourteenth day). The positive supporting reactions were very marked, and nystagmus, present during the first three or four days, disappeared entirely. There was definite hypertonia of all extremities throughout the period of observation.

Second Operation (Dec. 7, 1929).—Removal of left cerebral hemisphere. Again under diallylbarbituric acid anesthesia, the temporal muscle was turned back, and the left cerebral hemisphere was freely exposed and removed well down to the thalamus. The attempt was made to include all of the temporal lobe. The hemisphere broke as it was being taken out (fig. 3), and the hemorrhage was fairly severe.

Postoperative Observations.—Immediately after the procedure the animal showed a marked increase in rigidity on the right side, especially in the hind limb.

First Day: The animal was rapidly recovering from the anesthetic. The right pupil and palpebral fissure were larger than the left, and there was greatly increased rigidity in the right extremities. A slight pinch of the left hind foot caused the right limb to go into extensor spasms, and a similar crossed extensor reflex could be obtained from the fore limbs. No spontaneous movements were seen on the right side.

Second Day: The animal was taking food and fluid, and its general condition was good. The rigidity of the hemiplegic side was still marked, but it appeared to have diminished slightly. In moving about the cage the hemiplegic extremities were dragged along like stiff poles. The eyes showed fairly marked lateral nystagmus, with the slow component to the right, and a tendency toward conjugate deviation of the eyes to the left.

Third Day: There were marked spontaneous movements of the hemiplegic side, showing no trace of ataxia. The animal was observed on one occasion to execute an imperfect scratch reflex with the hemiplegic hind limb; this also showed no ataxia. The rigidity was diminishing.

Fourth Day: Rigidity on the hemiplegic side was still diminishing, particularly in the fore limb.

Ninth Day: There was still no trace of ataxia in the hemiplegic side.

Tenth Day: Positive supporting reactions were studied and were found still present on the left but not on the right, and the animal did not "correct" when its leg had slipped off the edge of a table. When the right hind limb was touched, one felt a definite extensor contraction, but it was quite unlike the magnet reflex seen on slight contact with the pads of the left hind limb. The knee jerk was exaggerated on the hemiplegic side. The animal's condition was entirely satisfactory when the third operation was performed.

Third Operation (Dec. 17, 1929).—Removal of right hemisphere. The right cerebral hemisphere was removed under diallylbarbituric acid anesthesia, in one piece (fig. 3). The reflex state after the removal of both hemispheres will be described in discussing the decerebellate thalamic preparation. Details of the autopsy are also given there (p. 25).

Two things thus emerge from our analysis of the semidecorticate decerebellate preparation: 1. The hemiplegic side becomes rigid, and

Fig. 3 (experiment 3).—A photograph of the two cerebral hemispheres and cerebellum as removed at successive operations, together with the brain stem removed at autopsy fourteen days after the last operation. The decerebellation had been complete.

though the rigidity ultimately diminishes it has, during its early stages, certain features in common with that of rigidity in the decerebrate state. The animal, however, eventually executes certain spontaneous movements, chiefly of the "associated" type. 2. When spontaneous movements occur, they are invariably free from ataxic tremor. A more detailed study of the semidecorticate decerebellate preparation with reference to postural reflexes will be published later in the series.

THE DECEREBELLATE THALAMIC PREPARATION

Of the five cats that had survived for a significant period following the removal of both hemispheres of the cerebrum, and the cerebellum, we propose to describe two in considerable detail and one of the other

three briefly, in order to emphasize only the chief features of the observations made on them. The first animal to survive the three operations lived longer than the rest and succumbed to a septic condition of the shoulder from a pressure sore. The history of this animal is as follows:

EXPERIMENT 4.—*Successive removal of the cerebellum, left cerebral hemisphere and right cerebral hemisphere, at intervals of about three months. Survival sixteen days after third operation. Much spontaneous activity with complete disappearance of cerebellar tremor during this interval.*

The subject of the experiment was a sexually mature, black, female cat, weighing 2,400 Gm., friendly, playful, in excellent physical condition and aged about 2 years. It was deft in its movements, and its gait was entirely normal.

First Operation (June 26, 1929).—Complete removal of the cerebellum. Under intraperitoneal diallylbarbituric acid anesthesia (1.3 cc. per kilogram), the cerebellum was exposed by the posterior approach without occluding the carotid arteries. The vermis was elevated, and the peduncles were cut through with a small curved knife. The cerebellum was then longitudinally dissected, and the whole organ removed in two pieces. A small amount of floccular tissue was allowed to remain intact on the left side in order to prevent undue hemorrhage. The animal's respiration was not disturbed during the operation, and the loss of blood was insignificant.

Postoperative Observations.—The postoperative course was, in nearly all respects, similar to that of experiment 1. Severe opisthotonoid seizures continued during the first two or three days, and periodic running movements were observed on the second day, unassociated with hypermetria or tremor. Nystagmus was present for the first week, but ultimately passed off completely. Swaying movements and tremor of the head began to appear on the fourth day and increased to a degree during the first ten days. The head assumed the horizontal posture on the fourth day, and the animal made no attempt to walk until the end of the first month. By that time extreme trembling ataxia was present in all four extremities whenever voluntary movements were attempted.

Forced Rolling Movements: During the first week the animal had periodic seizures of forced rolling movements in a counter-clockwise direction. They came suddenly, apparently without warning, and evidently were due to vestibular irritation. They passed off completely at the end of the first week, and at the same time nystagmus disappeared. There was rather marked hypotonia of all extremities, lasting from three to four minutes after such a seizure; otherwise, the extremities remained markedly hypertonic. The animal continued under observation in the decerebellate state for three months.

Ninetieth Day (Sept. 24, 1929): The animal remained quietly in its cage, but when set on the floor could be made to attempt walking by placing meat at some distance in front of it. She scrambled onto her feet, usually falling over several times, but always eventually succeeded in reaching the place. In attempting to pick up a piece of meat, there was an extremely coarse tremor of the head; usually she made several unsucccessful attempts before actually taking the flesh into her mouth. At times the positive supporting reaction could be obtained, but it was less marked than in other decerebellate cats. A slight pressure on the flexor group of muscles caused inhibition of the extensors.

Second Operation (Sept. 24, 1929).—Removal of the left cerebral hemisphere. As the animal's weight had become 2,300 Gm., 1.5 cc. of diallylbarbituric acid intraperitoneally proved an adequate anesthetic. The left hemisphere was exposed

by incising the temporal muscle near its origin. The occipital lobe was drawn forward, and the whole hemisphere was removed in two pieces by slicing down through the corpus callosum into the middle fossa with a spatula. A small piece of the inferior medial part of the temporal lobe was allowed to remain intact, but all connections were apparently severed. There was very little hemorrhage, and the animal was in excellent condition at the end of the procedure.

Postoperative Observations.—First Day: The animal was well out of the anesthetic twenty-four hours after the operation. It was seen resting in the cage on its right side (hemiplegic side), and the right extremities exhibited marked rigidity, much more so than in the cat from which only the hemisphere had been removed. There were periodic seizures of opisthotonos, associated with much greater extensor rigidity, both right and left. During such seizures the claws became widely spread on the normal side, but remained flexed on the right. The right pupil was larger than the left, and there was obvious right-sided blindness. Coarse tremor of the head persisted.

Third Day: The animal continued in excellent condition with evidence of marked right hemiplegia; it was sitting up and making attempts to get onto its feet, usually failing to do so, owing to weakness of the right side. Such movements as were executed on the hemiplegic side were wholly without tremor. When lifted, the hemiplegic extremities were stiff, and there appeared to be an increase of rigidity on touching the pads of the feet (positive supporting reaction). The disposition had altered, and the cat was likely to bite and scratch whenever it was touched.

Fourth Day: The cat was not yet able to stand, but moved about the cage much more actively than before operation. There seemed to be less tremor of the head and an increase in the amplitude of movement of the hemiplegic extremities.

Eighth Day: The cat was still unable to get onto her feet. The hemiplegic extremities still showed little purposeful movement. Emotional instability persisted.

Twenty-Fifth Day: During the interval, the animal had improved considerably with respect to movement of the hemiplegic extremities. However, it was obvious that removal of the cerebellum plus the hemisphere yielded a far more permanent and effective paralysis than ablation of the hemisphere alone. She now attempted to walk, but the right extremities were used more as props than as legs and were often allowed to lag behind during progression, with the result that the animal would fall over after taking a few steps. Ataxia of the head continued during rest. Opisthotonos had disappeared, and the rigidity of the hemiplegic extremities had diminished. Such movements as were executed by the right limb were inaccurate and at times quite purposeless, but they exhibited no trembling ataxia such as was seen on the left. The animal was still uneven mentally, and sat growling in the cage without adequate provocation.

The left hind limb reacted much more quickly to a small pinch than did the right; the latter, if it reacted at all, gave either a complete withdrawal or no response whatever.

Subsequent Course.—There was very little change in the neurologic condition of the animal during the next two months. On November 5 (thirty-fifth day), the scratch reflexes were observed on the hemiplegic side; they were perfectly coordinated and showed no evidence of tremor. On January 25 (one hundred and tenth day), before the third operation, the extremities on the right were still moderately stiff and showed very little spontaneous movement except when the animal was making an extreme effort to walk.

Third Operation (Jan. 25, 1930).—Removal of right hemisphere. Diallylbarbituric acid, 1.15 cc. given intraperitoneally, was again used for anesthesia, as the animal's weight was then 2,500 Gm. This was scarcely adequate and had to be supplemented with ether. The hemisphere was exposed in the usual way; the combination of ether and the scar tissue of a tertiary operation made the whole field fairly vascular. The removal of the hemisphere was accompanied by considerable hemorrhage. The olfactory nerve was left intact; great care was taken to remove all of the temporal lobe, and the hemisphere itself was extirpated down to, but not including, the thalamus.

Postoperative Observations.—First Day: The preparation recovered promptly from the anesthetic and became increasingly restless in the course of the day. During the afternoon it exhibited unceasing walking movements in which the extension of the leg was more ample on the right than on the left, and the movements themselves appeared to be well coordinated and without tremor. When walking movements were stopped by pinching the skin, the extremities tended to become stiff. Fluid (250 cc.) was injected intraperitoneally, and the animal was suspended in a hammock in the hope of preventing pressure sores.

Second Day: Walking movements still continued. There was some tendency toward opisthotonos, with curving of the body toward the left side. The extension of the extremities on the left was less extensive than that on the right. The left extremities also showed considerable edema. No tremor was to be seen in any movements, even in the head.

Third Day: Walking movements continued, and on this day the animal ate a large plate of raw meat, much as it had done before it was reduced to the thalamic condition. The mouth had only to be placed in the meat, and the plate was emptied in about a minute.

Fourth Day: It was evident that periods of activity separated the periods of rest, as in the acute thalamic animals described by Magnus[9a] and Schaltenbrand and Girndt.[12] The animal lay suspended in a hammock in a wooden box with its head protruding through one end. It remained quiet for seven or eight minutes and then without any apparent stimulation began to execute vigorous walking movements. At this time the pupils became dilated, the nictitating membrane disappeared, and the globes of the eyes came forward in their sockets. Occasionally there were snarling and growling.

Fifth Day: No change was observed.

Sixth Day: Running movements were still less ample on the left than on the right side.

Postural Reactions: When the animal was held on its back and gently restrained by supporting the abdomen and thorax, it usually passed at first into a violent opisthotonoid seizure. After this had passed off, the hind limbs began to execute fairly well coordinated rhythmic movements in which the fore limbs also participated, although their movements were less ample. All movements were greater on the right side.

When the pads of the feet, especially those of the hind limbs, were gently touched, the rhythmic movement ceased immediately in all four extremities, and the limb touched became vigorously extended. Usually during periods when the animal was resting with the limbs flexed, a gentle contact with the foot in such a

12. Schaltenbrand, G., and Girndt, O.: Physiologische Beobachtungen an Thalamuskatzen: I. Allgemeines Verhalten im akuten Versuch, Arch. f. d. ges. Physiol. **209**:333, 1925.

way as gradually to extend the ankle provoked a slow but forceful extensor response which caused the limb to follow one's finger. During movements these reactions failed to occur.

Righting Reflexes: Only the labyrinthine righting reflexes were tested, and visual stimuli were not excluded. In all positions of the body the head tended to assume the horizontal posture quickly, fairly accurately and without tremor.

Locomotion: When placed on its four feet, the preparation often maintained the position for some time without falling over and occasionally attempted to walk, but after one or two steps it usually fell. There was no tremor, and one could not describe the gait as ataxic; the movements were simply not executed with sufficient harmony to keep the animal on its feet. The movements were altogether different from those of a decerebellate animal the hemisphere of which is intact. The legs exhibited considerable extensor tone, and from time to time there were marked accessions of rigidity in the hind limb, sometimes without obvious cause, but always occurring when the tail was pinched. Pressure on the end of the tail caused the hind limb to become vigorously extended and gave a most grotesque posture.

Feeding: The feeding reactions of the preparation grew increasingly pronounced and were a rather surprising sight. The effective stimulus to feeding seemed to be a combination of smell and the contact of the muzzle with food. One gained the impression, however, that the animal became aware of food before it had actual contact with the lips. Once its muzzle was put into a plate of chopped-up raw meat, it began to bolt enormous quantities and to bolt them without any mastication whatever. Had we allowed it to do so, it would undoubtedly have distended its stomach to an alarming degree. Once the process of swallowing was commenced, the animal bit anything that was put between its teeth, on one occasion chewing for some minutes on the edge of an enamel plate. The stimulus to lapping fluid also was readily evoked, and on several occasions the animal drank 30 or 40 cc. of cold water from a cup. This day was the first occasion, however, when fluid was taken spontaneously.

Seventh Day: Analysis of spontaneous movements: Careful study of the animal's movements when lying on its side showed clearly that they were part of the abortive righting reflex. Thus, when on its recently hemiplegic side (left), the extremities on the right executed vigorous rhythmic movements directed toward putting the animal on its feet. When on its right side or placed in a horizontal position on all fours, these rhythmic movements did not occur. So long as the animal remained in an erect sitting posture, rhythmic movements were not seen. However, when it was suspended in a hammock, even though it was horizontal, they were likely to occur.

Subsequent Course.—After the tenth day, the general state of the animal remained practically constant. It was difficult to keep her quiet and almost impossible to prevent decubitus ulceration during the night. It was prone to assume strange postures, and even when slung in a hammock and put in a box it would scratch its fore paws with the hind and cause subcutaneous infection. It continued, however, to feed voraciously until the fourteenth day, after which an ulceration on the left shoulder gained the upper hand, and the animal began to go downhill. On the tenth day, it was observed that once the feeding reflex was started the animal appeared to go on swallowing indefinitely until some strong nociceptive stimulus caused it to stop. It would often drink 50 cc. of fluid at one sitting, which is unusual for a cat.

Various reflexes were carefully studied and recorded, such as the responses of the pupil, knee jerk, etc., but as these were in harmony with the carefully studied case of Rademaker's decorticated dog and since the reactions did not seem to be influenced by the absence of the cerebellum, we do not propose to record them here.

At noon of the sixteenth day, the animal was found dead in the cage, still warm.

Autopsy.—Formaldehyde was injected into the central nervous system through the left side of the heart, and the brain and spinal cord were removed immediately afterward. The cranial cavity on the right side was filled with clear yellow fluid, which on exposure to air clotted and became somewhat pinkish. There were no adhesions between the internal surface of the temporal muscle and the cut surface of the brain stem. The left cranial cavity was also filled with fluid, thicker, darker

Fig. 4 (experiment 4).—The ventral surface of the brain stem, showing the portions of the medial temporal lobe still intact on both sides.

and less in amount than that on the right, and a few adhesions were present between the temporal muscle and the brain stem. The posterior fossa was lined with a particularly thick fibrous sac containing here and there small patches of calcification. The medulla was smooth and in good condition and contained a spherical, old blood clot, 4 mm. in diameter, which had been floating freely in the fourth ventricle.

After hardening for several months in formaldehyde, the brain stem was carefully depicted in a half tone from the dorsal and the ventral surface (fig. 4). It was then sectioned, and the state of the tissue was as follows:

Cerebellum: The cerebellum had been completely removed except for a small tag of the left lateral cerebellar lobe, which was intact and connected only by a few pontile fibers (fig. 4). The conjunctivum and the posterior cerebellar peduncles had been cut entirely through on the right side.

Forebrain: The left half of the thalamus, and a greater part of the left temporal lobe and a small part of the base of the left olfactory region were intact. The left parietal and occipital lobes had been completely removed. On the right, there were hemorrhagic lesions and softening of the portion of the thalamus involving the pulvinar and lateral nucleus. The whole of the right hemisphere had been removed, except a small part of the ventrolateral portion of the temporal lobe which was not connected with the rest of the brain.

Spinal Cord: Sections at the sixth and twelfth dorsal segments stained by the Marchi method showed in both levels extensive degeneration in the region of the left pyramid and faint degeneration of the right pyramidal area. The area of degeneration could also be seen with the naked eye.

This experiment illustrates a number of points, but it is particularly striking on account of the complete absence of tremor following the third operation. Surgically, it represents one of our earliest attempts to extirpate the cerebral hemispheres, and fairly large pieces of cortical tissue were found subsequently to be present at the base on both sides (fig. 4). We conclude, however, that the region of the cortex responsible for cerebellar tremor had been destroyed. On account of the incompleteness of the extirpation, we did not go to the expense of making serial sections of the brain stem. Complete sections are being made of the brain stem in experiment 3, as the extirpation was more satisfactory.

The condition in experiment 3 following the third operation will now be described. The reactions were essentially similar to those in experiment 4, apart from the vigorous auditory responses.

Experiment 3 (Continued).—*Third Operation. Removal of remaining right cerebral hemisphere; survival for fourteen days, with vigorous locomotor movements and complete absence of tremor.*

Third Operation (Dec. 17, 1929).—The weight of the animal was 2,350 Gm. before the third operation, and a dose of 0.75 cc. of diallylbarbituric acid intraperitoneally proved adequate: although the preparation vocalized throughout the procedure, the tone and frequency of the vocalization were in no way altered while the remaining hemisphere was being extirpated. It was taken out in the usual way by withdrawal of the occipital lobe forward and a section of the corpus callosum. There was very little bleeding, and nothing remained intact of the hemisphere apart from a small tag of the temporal lobe, which was not interfered with, in order to avoid hemorrhage from the base. The olfactory nerves were destroyed.

Postoperative Observations.—Same Day: Respiration had changed very little during the operation, and when the animal was undraped it was still licking its nose. The nictitating membranes were completely relaxed, and the pupils were dilated. Whenever the animal was touched it began to execute fairly rapid walking movements which were carried out in rhythmic sequence without tremor. The extremities were not particularly rigid.

First Day, 10:00 a. m.: The preparation was recovering rapidly from the anesthesia. It lay on its side, executing walking movements continuously. When placed in the horizontal position, it retained the posture for several minutes and then fell backward and began again to walk. The nictitating membranes were still relaxed. A small amount of fluid was taken by mouth.

6:00 p. m.: The walking movements still continued. The animal was much more active than in the morning. There was no further vocalization; spontaneous nystagmus was noted, chiefly vertical in character.

Positive supporting reaction: Slight contact with the pads of the feet, made in such a way as to place the extremities under tension, provoked a vigorous extensor thrust which continued as long as contact was maintained. Pressure which tended to flex the toe pads usually produced flexion, presumably the so-called "negative" supporting reaction.

Second Day, 11:00 a. m.: The preparation was much brisker than yesterday, showing, however, intervals of profound somnolence alternating with phases of great activity. During the spells of activity, vigorous walking movements were seen, and the animal occasionally attempted to lift its head. From time to time spasms of opisthotonos occurred, usually with some pleurothotonus to the left. When asleep, the pupils were sharply constricted, and when awake they were dilated, often maximally. After being handled for a few minutes, the preparation would sink back into the cage apparently exhausted.

Auditory responses: Any sudden noise in the vicinity of the animal made it jump vigorously, sometimes raising it from the cage. A first sound always gave a much more vigorous response than a second sound of similar intensity repeated at a brief interval.

Supporting reactions: They were less brisk than on the preceding day, but during periods of activity they were readily demonstrated. During somnolence the response could not be obtained. Professor Sherrington drew attention to the marked labyrinthine reaction when the animal's position in space was altered, but if held with the legs hanging pendant there was very little rigidity in the extremities. However, when held prone the legs stuck rigidly into the air, and when held vertically they were also rigid, and even the muscles of the tail took part in the response.

Vasomotor disturbances: During the entire time since the third operation the left ear had been noticeably red and warm as a result of dilatation of the superficial vessels. On measuring the temperature, it proved to be 5 degrees warmer than the right. The pads of the feet on the left were also somewhat warmer than those on the right.

Third Day: The difference in temperature between the two sides of the body had practically disappeared; the animal was much brighter; the nictitating membranes were no longer in evidence, and the globes of the eye showed good tension. Intervals of rest and activity still were evident.

Lack of tremor: As this was the first preparation in which the absence of tremor was observed in the decerebellate thalamic preparation, we may quote directly from our protocol. "The one outstanding feature distinguishing this preparation from other decerebellate preparations with one or both hemispheres intact, is *the complete absence of tremor*, especially of the head during rest. The previous notes on this animal and others of this series have directed attention to the constant resting tremor of the head, and the marked tremor of the extremities on attempted motion. With this preparation, all tremor has now ceased completely despite the fact that it executes regular walking movements even during sleep. Irritation behind the ear evoked a well coordinated scratch reflex. The animal, however, is not able to stand and when placed on its hind extremities they both become rigid and pillar-like and are quite capable of supporting a weight at least ten times as great as the animal itself. When left without support the creature invariably tumbles over."

Auditory stimuli: Any sudden noise still evoked a vigorous response, affecting extensors and flexors alike, although the flexors seemed to contract somewhat more vigorously; even the tail twitched.

Positive supporting reactions were still present, especially when the animal was awake.

Vocalization: Normal meowing sounds were heard several times during the day. When attempting to open the mouth to feed the cat, there were vigorous outbursts of growling and hissing.

Feeding: It took water spontaneously and swallowed small quantities of red meat, but apparently opening the mouth gave rise to nociceptive reflexes.

Labyrinthine reflexes: These were similar to those described for the preceding day. When placed in a vertical position, vigorous running movements were caused and seemed to be fairly well coordinated.

Fourth Day: The animal was not studied.

Fifth Day: The activity of the preparation was increasing, and it threw itself about the cage so frequently and so vehemently that we feared it would do itself damage. All movements seemed to be in the nature of righting reflexes, uncontrolled and overvigorous. From time to time it succeeded in getting the forepaws underneath it, but the hind limbs were continually stiff and apparently immobile. When placed on the back, the head became markedly retracted, walking movements appeared, especially in the fore limbs, and the preparation attempted to right itself. There was "clasp-knife" rigidity in the hind limbs, but vigorous reflex flexion could be induced by pinching the tendo achillis or the hamstrings. The preparation spat and growled whenever disturbed. The general condition was entirely satisfactory.

Sixth Day: During the spells of continuous walking, the animal had produced severe abrasions of the fore limbs, and several serious sores had resulted. The condition, in respect to reflexes, was essentially unchanged from the third day, except that the hind limbs appeared to show somewhat more extensor rigidity, and the "clasp-knife" phenomenon (the "lengthening" reaction) could still be demonstrated.

Subsequent Course.—During the following weeks, the animal remained in essentially the same reflex condition, but it grew difficult to feed and, despite taking very large quantities of milk and raw meat, it went progressively downhill, losing weight and showing diabetic urine throughout this period. Periods of retraction of the head alternated with phases of locomotor movement; no trace of tremor was seen at any time.

Fourteenth Day (December 31): The animal was found dead in the cage.

Autopsy.—The wounds were well healed, and very little reaction was to be seen about the silk sutures. There was no meningitis, and the cavities occupied by the cerebellum and cerebral hemispheres were filled with clear, slightly yellow fluid. Death was evidently due to some profound metabolic disturbance incident to the removal of the second hemisphere. The abrasions of the feet were not sufficiently severe to account for death. The brain stem and spinal cord were removed, and, after hardening, the following conditions were disclosed:

The medulla was intact and uninjured; the cerebellum had been completely removed from both sides, there being almost no remaining tags of cerebellar tissue in either angle. The thalamus, hypothalamus and basal olfactory area were intact, and the two cerebral hemispheres had been completely removed except for a very small portion of both temporal lobes, which were still connected with the forebrain rostrally. The decortication had been much more complete than in experiment 4, and the decerebellation had been entirely complete. All thalamotemporal radiations had been severed.

The tissue, along with the hemispheres and cerebellum, removed at operation is shown in figure 3. A drawing of the base of the brain (fig. 5) indicates the amount of tissue of the temporal lobe still remaining intact (see also fig. 6). Serial sections of this and other similar preparations will be reported at a later date.

The next experiment amply confirmed our results in the previous two, and as the survival period was thirteen days, we regard the observations as significant. The difficulties of nursing as usual proved too great and were responsible for the ultimate death of the animal; it became progressively more emaciated, despite a fairly liberal intake of food and fluid.

With this animal we altered the sequence of operation, removing one cerebral hemisphere first and after that the cerebellum. The resulting semidecorticate decerebellate preparation was similar to those already

Fig. 5 (experiment 3).—The ventral surface (for dorsal surface, see fig. 3) of the brain stem, showing the small tags of the medial temporal lobe still intact on both sides.

described, although it was somewhat slower to recover from the cerebellar operation than when this was carried out as a primary procedure. Also the hemiplegic rigidity was much less marked than with the other sequence.

Experiment 5.—*A young male, tortoise-shell cat, weighing 1,400 Gm.; successive removal of right cerebral hemisphere, cerebellum and left cerebral hemisphere at intervals of seven weeks; survived thirteen days after operation, with complete absence of tremor.*

First Operation (March 17, 1930).—Removal of right cerebral hemisphere. Under ether anesthesia, the right cerebral hemisphere was freely exposed and quickly removed by a single slice passing through the corpus callosum and including the basal part of the frontal lobe and most of the temporal lobe. Following the extirpation, hemorrhage, though not overwhelming, was much more brisk than with diallylbarbituric acid anesthesia. After the extirpation the gasserian ganglion was

visible at the base of the skull; the circle of Willis, the pituitary stalk and the optic chiasm were also seen.

Postoperative Observations.—The animal was up and in good condition an hour after the procedure and exhibited the usual symptoms of contralateral weakness and circling toward the side of the lesion.

First Day: The animal was up and walking about, dragging the left extremities, but it was quite well able to stand and circled constantly to the left in a small radius. From time to time it toppled over to the left side. When the left fore limb slipped off the edge of the table, the cat made no attempt to correct.

Reactions of pupils: The left pupil was larger than the right, and both responded to light, the consensual reflex being strongly present from right to left, but absent from left to right. The blink reflex was completely absent on the left and was strongly present on the right.

Subsequent Course.—The animal, during the next three weeks, rapidly recovered strength and had acquired fairly adequate locomotor control of the right legs at the end of the third day. When it was blindfolded it rotated to the right instead of to the left, in keeping with the observations of Schaltenbrand and Cobb. A week after the operation it had a severe attack of distemper from which it recovered completely. Before the third operation, position sense was completely absent on the left side, although motor power appeared essentially normal.

Second Operation (May 10, 1930).—Removal of cerebellum. As the animal's weight was now 1,300 Gm., a dose of 1.1 cc. of diallylbarbituric acid was used intraperitoneally, which proved adequate, although there was weak vocalization throughout the procedure. The cerebellum was readily exposed by the usual midline approach, and on elevating the vermis both peduncles were completely cut through and the cerebellum was removed in one piece, all tissue in the lateral angles being completely destroyed.

Postoperative Observations.—First Day: While sleeping, the animal was observed to lie in an opisthotonoid position, with the fore limbs extended and the hind limbs flexed. It was motionless apart from the spasms of the opisthotonos and brisk crossed extensor reflexes which could be readily elicited on either side. No positive supporting reaction was seen, owing to the rigidity of the extremities; the rigidity was practically equal on the two sides.

Second Day: Opisthotonoid seizures still continued, but the animal was not carefully studied.

Third Day: The preparation was well out of the anesthetic and took water by mouth. The reflex condition was essentially unchanged; no tremors were seen; the rigidity was apparently somewhat greater on the left side than on the right.

Subsequent Course.—The animal was slow to pick up and difficult to feed, and it was nearly two weeks before it began to assume the horizontal position in the cage. Opisthotonoid seizures continued during the first month. At no time was there marked difference in the rigidity between the extremities of the two sides, which is in striking contrast to the greatly increased rigidity that comes on when the cerebellum is removed first.

Tremor as such did not begin to appear until the fourth week. On June 7, the animal had begun to assume the horizontal position in the cage, but was unable to walk. A coarse shaking tremor of the head and occasional weak opisthotonoid seizures were observed. Positive supporting reactions were present, particularly on the right side, but no scratch reflexes were observed. The tremor increased in extent, and ultimately, before the third operation, the animal began to get up on its four feet (July 1).

Third Operation (July 1).—Removal of left cerebral hemisphere. The cat now weighed 1,500 Gm., and with a dose of 0.7 cc. of diallylbarbituric acid the left cerebral hemisphere was completely removed down to the thalamus, but the olfactory nerve and olfactory radiation were allowed to remain. As in the previous experiment, the animal tended to vocalize throughout the procedure in a curious high-pitched way, with no alteration of pitch or frequency as the second hemisphere was being removed. The cry was therefore definitely extracortical, and as the removal was deep, one must assume that the crying reflex in this case was mediated by some thalamic or hypothalamic center.

Postoperative Observations.—First Day: The animal was still somewhat anesthetized, and nothing striking was observed apart from fairly well marked flexor tonus and occasional spontaneous movements that exhibited no tremor.

Second Day: The preparation was much brighter and more active than on the preceding day, and flexor tonus was still observed in all four extremities. The animal showed spasms of opisthotonos which were much more severe than in any

Fig. 6 (experiment 3).—Cross-section of the brain stem at the level of the infundibular stalk, showing the intact thalamus, hypothalamus and medial temporal lobe, but partial destruction of the lenticular nuclei.

of the other animals that we had observed. The pupils were still small, and the nictitating membranes were relaxed. The spontaneous movements, which were much more brisk than on the previous day, still failed to show any tremor. Crossed extensor reflexes were still particularly vigorous and could be obtained on slight pinching of the pad. The knee-jerks were active and apparently equal. Gentle pressure on the pads of the hind limbs evoked an unmistakable positive supporting reaction, which was well sustained and not unlike that seen shortly after decerebellation.

Third Day: The animal now showed alternating periods of activity and rest similar to those in experiments 3 and 4, being very active for two or three minutes and then falling to sleep (pupils constricted). During activity the pupils were always dilated, and there were occasional outbursts of sham rage. The animal had begun to drink large quantities of fluids and was commencing to take solid food. Reflexes, positive supporting reactions, etc., were unchanged from the previous day, apart from the righting reflexes.

Righting Reflexes: The animal had already begun to assume a horizontal posture and tried to right itself whenever it was put on its side. It moved about the cage much more vigorously than before the third operation.

Auditory Responses: Hyperacusis was most evident, and any sudden sound caused the whole musculature to jerk. As with the other preparation, a given sound quickly diminished in effectiveness.

Marked shaking of the head and scratch reflexes were observed, always without tremor.

Fourth Day: The animal was exhibited before the Physiological Society. Its general condition remained satisfactory.

Feeding: On the preceding night the animal had taken solid food; on this day it consumed, in the course of the afternoon, while being demonstrated, nearly 200 cc. of milk. In order to start the drinking reflex, the muzzle had to be put in the fluid, and the cat then commenced slowly lapping; the reflex reached its full intensity after about thirty seconds. It would go on indefinitely until some other strong

Fig. 7 (experiment 5).—Decorticate thalamic preparation as it appeared twelve days after the third operation. Note that the righting reflexes are present and that the eyes are open. The animal was unable to walk.

form of stimulation interrupted it. During periods of activity, the cat was capable of climbing out of the box, which was about 1 foot in height. Vocalization was readily elicitable on pinching the tail. There was also periodic purring.

Fifth Day: The pupils were tested and found to react fairly vigorously to light, but the consensual reflex was poor from right to left. The nystagmus, which was observed during the first few days after operation, had disappeared. The animal was still eating and drinking voraciously, climbing actively about the cage, and we feared that it would do itself injury.

Sixth Day: The righting reflexes were still overactive, and any sudden change in position caused an outburst of running and struggling movements.

Seventh Day: The preparation had become so active that it was almost impossible to prevent pressure sores in the course of the night. It would lie in one position, executing walking movements constantly, and patches of inflammation developed on any exposed surface against which the extremities rubbed.

Eighth Day: The animal was thrashing about, and despite the fact that it was eating voraciously, it was evidently losing weight. It drank huge quantities of water, particularly after periods of rage. During sham rage, the pupils would dilate, the globes bulge and the heart accelerate, and the animal would exhibit all the features described by Bard and Cannon.

Ninth Day: The animal's claws were cut, as it had begun to gouge itself in the abdomen and fore extremities.

Twelfth Day: The animal was still very active; it could be placed on its fore limbs in the horizontal position and would stay there for fairly long periods of time, without tremor or difficulty; then it would gradually sink down with the fore feet extended before it like the lions in Trafalgar Square (fig. 7), and would remain in this position for indefinite periods of time. Marked opisthotonoid seizures were still occurring, and the positions shown in figures 7 and 8 were assumed on this day.

Thirteenth Day: The animal had been well on the previous day and had fed freely, although we were aware that it was emaciated; on this morning it was found dead in the cage.

Fig. 8 (experiment 5).—Decorticate thalamic preparation twelve days after the third operation, showing spontaneous opisthotonoid seizure.

Autopsy.—Despite the emaciation, bronchopneumonia appeared to be the immediate cause of death. After several days' fixation in 5 per cent solution of commercial formaldehyde the brain was examined, and the findings were as follows: The cerebellum had been completely removed, apart from a small tag of floccular tissue on the left side. The right half of the forebrain had also been removed in its entirety, with destruction of the rostral half of the right thalamus and the greater part of the right basal olfactory area. The caudal portion of the thalamus remained, including the two geniculate bodies and the hypothalamus. There was no trace of a striatum or a pyriform lobe. The left cerebral hemisphere had been incompletely destroyed, the temporal lobe being intact in its medial portion and also the hippocampal radiation. The thalamus, hypothalamus and left olfactory areas were present, together with the ventral portion of the left striatum.

COMMENT

That the cerebellum is not an essential part of the nervous mechanism involved in tonic neck, labyrinthine and righting reflexes has been established by the observations of several observers (Magnus,[9a] Pollock

and Davis,[13] Rademaker [1g] and others). That it plays a definite rôle, however, in controlling these mechanisms in acute preparations has been shown by Pollock and Davis.[13] These authors found that in acute decorticate decerebellate cats the postural and righting reflexes were distinctly overactive. In acute decerebrate decerebellate cats they found the "rebound" phenomenon greatly increased over that seen in decerebrate cats. The results of the experiments described here extend the conclusions of Pollock and Davis to the case of chronic decorticate preparations. The present results show in addition certain other symptoms apparently due to the loss of the cerebellum, e. g., marked spasticity with very slow recovery on the hemiplegic side in semidecorticate decerebellate animals, increased extensor tone, incoordination of movement with inability to walk, jump or spring and very slow, partial recovery in the decorticate decerebellate preparations. It may therefore be concluded that the cerebellum plays an active rôle in controlling certain lower centers that have to do with postural reflex patterns. There are other centers, however, over which no cerebellar control has been demonstrated, e. g., the centers for the scratch reflex, the withdrawal response, etc. (Dusser de Barenne [1e] and Pollock and Davis [13]).

In view of this cerebellar control over the postural reflexes, it is significant to find that tremor, which is one of the most striking symptoms in the decerebellate cat, is entirely absent in the decorticate decerebellate preparation. This is in keeping with the observations of Munk,[14] Dusser de Barenne [1e] and Walshe,[5] who showed that cerebellar tremor is present only in voluntary movements. Dusser de Barenne went further, however, in stating that cerebellar tremor appears only in certain voluntary movements and is absent in those voluntary movements in which little or no postural activity is involved. On the basis of the results described in this paper and of the observations of these authors, one may conclude that the nervous mechanism involved in the phenomenon of cerebellar tremor includes some part, at least, of the cerebral hemisphere (evidence for a more definite localization, the motor cortex, will be presented in a future paper).

The question as to how the cerebral hemisphere takes part in the genesis of cerebellar tremor is still a matter of speculation, and a number of hypotheses that would fit the available data are conceivable. It may be worth while briefly to outline here one such hypothesis, which has the advantage of suggesting a new line of attack on the problem.

13. Pollock, L. J., and Davis, L.: The Influence of the Cerebellum upon the Reflex Activities of the Decerebrate Animal, Brain **50**:277, 1927; The Reflex Activities of a Decerebrate Animal, J. Comp. Neurol. **50**:377, 1930.

14. Munk, H.: Ueber die Functionen von Hirn und Rückenmark, Berlin, A. Hirschwald, 1909.

According to this hypothesis, the cortex, in the decerebellate animal, "takes up" the function of the lost cerebellum and, to a greater or lesser extent, compensates for it, particularly in regulating the postural reflexes (such compensation on the part of the cortex for the loss of the cerebellum is exemplified by certain cases quoted by Demole [15]). In Demole's cases a congenital lesion of the cerebellum was symptomless until a later cortical lesion produced cerebellar symptoms. The degree of completeness of compensation by the cortex would probably be greatest when the destruction of the cerebellum was most gradual. When compensation is incomplete, as it is almost certain to be with rapid destruction of the cerebellum, tremor results during voluntary movement involving postural activity, the genesis of the tremor being cortical.

SUMMARY

The present contribution, which represents the first of a series dealing with the relation of the cerebrum to the cerebellum in various mammals, including monkeys and the higher apes, is concerned with the genesis of cerebellar tremor in the cat. The results may be summarized as follows:

1. In the cat, following complete decerebellation, tremor does not appear until the third or fourth day (muscles of the neck), and is not fully developed until eight or ten days after the operation.

2. Involuntary opisthotonoid spasms are unassociated with tremor.

3. No tremor is seen until the animal attempts to move voluntarily.

4. When one cerebral hemisphere is removed, the extremities on the opposite side pass for several days into a state akin to decerebrate rigidity. Well marked associated movements ultimately appear in the hemiplegic extremities, but no tremor is seen.

5. When both cerebral hemispheres are removed, thus producing a thalamic preparation without a cerebellum, vigorous locomotor movements occur quite unassociated with tremor.

6. In the semidecorticate and decorticate preparations without a cerebellum, there are a marked increase in extensor tone, overactivity of the righting and postural reflexes and incoordination of movement, so that the animal is not able to walk. The recovery of these animals is much slower than in decorticate preparations with the cerebellum intact.

CONCLUSIONS

1. The cerebellum exerts a controlling influence over the postural reflexes in chronic decorticate cats.

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15. Demole, V.: Structure et connexions des noyaux dentelés du cervelet, Schweiz. Arch. f. Neurol. u. Psychiat. **20**:271, 1927.

2. The cerebral hemisphere is an integral part of the nervous mechanism responsible for the genesis of "cerebellar tremor."

ABSTRACT OF DISCUSSION

Dr. Henry Alsop Riley: It is difficult for me adequately to discuss Dr. Fulton's paper. There is no particular approach to the work that he has done through the small piece of work that I did some years ago on the comparative anatomy of the cerebellum. This is a matter for neurophysiologists to discuss. Perhaps because my training has not been in experimental physiology, I have a definite feeling of distrust of these major operative procedures on the highly organized central nervous system, a system that has taken millions of years to bring into being and one that has developed by the pyramiding of one level on another, each one of them actively interrelated and cooperating with the other. When one considers the enormous disturbances in function that a simple lesion will produce, I think it staggers the imagination to think of what goes on in the nervous system of any animal that has first had half of the cerebellum removed and then a considerable amount of cortex. It seems to me that there is so much interlinking between the various areas in regard to excitation, depression, substitution and other functions that it is well nigh impossible to come to any definite conclusion as to what each particular center is actually contributing to complex functions and to arrive at any definite physiologic explanation of what one has accomplished by these extensive mutilations of the nervous system. Of course, eventually we may arrive at a solution of these riddles. It certainly seems to me that while the experimental investigation of the nervous system has produced an enormous number of facts, it has done very little actually to elucidate the complex linkages that take place in the nervous system, and it would also seem to me that though it is a slower process, the deranged activity of nature will be explained by careful and detailed histopathologic investigation rather than by these procedures, which do such enormous damage to this complicated mechanism.

Dr. J. Ramsay Hunt: Dr. Fulton's extirpation experiments are extremely interesting. I remember Walshe's discussion of cerebellar function, which harmonized in some respect with my own views, viz., that the intention tremor after ablation of the cerebellum is a compensatory manifestation in the kinetic sphere, the static component of motility that is represented in the cerebellum having been removed. In the one case that Dr. Fulton described in detail, extirpation of one half of the cerebellum was performed in a baboon; this was followed by a typical cerebellar disturbance of the function of the arm and leg on the same side which, according to my view, is dependent on the removal of the static or postural function of the cerebellum. There was some degree of astasia and intention tremor, but associated with preservation of movement in the affected extremities, the motor disorder manifested itself by a diminution of static or postural stability. Subsequently the rolandic and striatal areas on the opposite side were removed, which had as a result an almost complete paralysis of the affected extremities. Here, according to my view, the cortical and striatal or kinetic components of motility were removed, so that practically all voluntary movement was abolished. These experiments, therefore, would appear to support my theory of the duality of the efferent system.

In recent years, experimental physiology in England, under the aegis of Sherrington, has made remarkable advances in the field of the somatic innervation of striated muscle fibers, and it would appear from the experimental investigations of Denny-Brown that there are two types of muscle fibers, the quick contracting

white fibers, in which the stimulus threshold is high, and the slow, red postural fibers with a much lower threshold of discharge. In striated muscles, therefore, there are some fibers that subserve the function of movement (motion fibers) and others that subserve the function of posture (posture fibers), these differing in their histologic characteristics and electrical theshold of discharge. It has seemed to me that these findings at the neuromuscular level may be harmonized with my views of kinetic and static systems at higher levels, the corticospinal and the striatospinal divisions of the kinetic system controlling the motional muscle fibers and the cerebrocerebellar and cerebellospinal divisions of the static systems regulating the function of the postural muscle fibers. Dr. Fulton's results might be explained on this basis.

The removal of half of the neocerebellum produces a defect that I should regard as a postural defect. When the rolandic area and the striatum are removed, which control kinetic function, there are produced as a result a paralysis and a greater degree of motor disability than if the cerebellum alone is removed. In other words, removing the central mechanisms of motility, one postural and the other motional in its function, has a greater effect than when one alone is removed, and it seems to me that there is now support at the muscular level for this point of view since the work of Denny-Brown. I should be glad to know whether Dr. Fulton thinks that such an explanation has any validity, and, if not, what his explanation would be for these interesting findings.

Prof. F. H. Pike: In defense of the experimentalists, one might say that nerve fibers look very much alike when they are stained. They are strangely reticent as to the character of the impulses that they carry and as to the peripheral source of these impulses. The dorsal and ventral roots of the spinal cord were regarded for a long time anatomically, but it was Bell and Magendie who showed experimentally that it was the dorsal roots that conveyed the afferent impulses and the ventral roots that conveyed the motor. Of course, we damage the central nervous system by experimental operations, sometimes to lesser and sometimes to greater degrees than in neurosurgery on human beings, and sometimes a little less than that which results from disease processes. I think that the experimental method is the best we can do just now. I think that all of us appreciate that the nervous system is a complex mechanism. I have pointed out [16] that, without any great anatomic refinement, one can easily pick out a hundred different structures in the nervous system. Taking them one at a time, there are at least a hundred experimental procedures one can do, and taking them together, the number rises to ten thousand. There are few of us who have done that number. The possibilities are many, and while the experimentalist cannot see how things are linked together, he can see only the complexity of the problem, which requires much more work. Possibly he is no worse off than the morphologist or the clinician.

The fact that the effect of two successive lesions is somewhat greater than the sum of the effects of either one alone is not exactly what one might expect from current views. Here is a matter of importance. It is possible to make a median incision in the midbrain and sever the connections of the rubrospinal tract. If that alone is done, the animal reacts and gets about pretty well. It is possible to remove the motor area. If that alone is done, the animal again gets about fairly well, but if you do both, the animal is in a bad way.

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16. Pike, F. H.; Elsberg, C. A.; McCulloch, W. S., and Chappell, M. N.: Some Observations on Experimentally Produced Convulsions: II. The Type of Convulsions Elicitable After Lesions of the Rubro-Spinal System, with Some Incidental Findings, Am. J. Psychiat. **10**:567, 1931.

Perhaps there is another element that comes up in this cerebellar discussion. If a lesion is made in the vermis of the cat's cerebellum, there is a tremor of the head that persists for some weeks and perhaps for some months; it finally becomes greatly reduced in intensity, and eventually almost disappears. If after this time, say a year or two after the original injury, one removes both internal ears, the cerebellar symptoms, as regards the movements of the head, reappear in almost their original intensity. I have never seen any permanent recovery from that condition. Ordinarily, taking out both internal ears does not lead to any permanent tremor of the head.

Prof. Oliver S. Strong: The comment attributed to Dr. Walshe about the "obvious" interested me, because the same adjective may, at times, be applied to deductions from well known anatomic relations. Anatomy clearly shows the great importance of the connections between the cerebellum and pallium in the higher mammals. These connections are not only in the descending direction, i. e., from pallium to cerebellum, via the massive palliopontocerebellar paths, but apparently also from cerebellum to pallium, via the superior peduncular red nuclear and thalamic paths. If this latter is true, it would indicate not only that the principal cerebellar activities are under pallial control, or at least operate in conjunction with the pallium, but that the combined action of the cerebellum and pallium is principally of a reciprocal nature. This would seem to lead further to the interesting conclusion that the pyramidal outflow may contain a cerebellar component. In any case, the massive nature of these connections would lead one to expect that decerebration would result in the annihilation of most of the movements in which cerebellar ataxia would manifest itself.

In spite of this, one would expect some ataxia in the "pseudo-affective" activities of the thalamic animal, but I understand there was none. Dr. Pike has shown me animals with cerebellar lesions only, which showed marked cerebellar ataxia in all movements, including those of an "affective" character. The presence of cerebellar ataxia in the latter and its absence in the thalamic animals would tend to establish the validity of the distinction between "pseudo-affective" activities in the thalamic animal and true affective activities in the animal with a pallium, in which pallial activities contribute to the picture.

Dr. J. F. Fulton: In reply to Dr. Ramsay Hunt's question about the red and white fibers, I do think it is probable that the cerebellum exerts a more intimate control over the red than it does over the white fibers in the normal animal. This, of course, is pure inference, but I think it may be interesting to know of the recent experiments of the Italian investigator Patrizi, who found that the duration of twitch contraction of muscle altered markedly following complete decerebellation. I do not know just what this means, but it is a suggestive observation and is in line with the observation that removal of the higher centers in a frog changes the peripheral chronaxia. That suggests a type of influence on the lower motor neuron that has been suspected, but has never been previously demonstrated, and I think it indicates a line of experimental approach that may be valuable.

Dr. Riley, I think, said more than he really means, because if he were literally interpreted, progress in knowledge of the nervous system would be limited to chance observation. The experimental approach to the nervous system, it seems to me, is the one approach that allows one with certainty to make new knowledge—if I may use that term—but I agree that extirpations represent only one aspect of the experimental approach.

The challenge to the surgeon approaching experimental neurology is the challenge that Dr. Riley has made; namely, that we must do our work delicately. The improvement that we are going to make in the future will come through the

development of a fastidious surgical procedure. Our chief pride is to be able to make a sharply circumscribed lesion, and to operate again six months or a year later and find that the lesion is just where we made it, and not spread over half the cortex, and that the degeneration of fibers, e.g., in the pyramidal pathway, originates only in the part in which the lesion was made. This is very difficult. We often find more degeneration than could be expected, particularly when we make spinal lesions, and, after all, that is merely a reflection on one's surgical methods; but as one improves I think that the protest that Dr. Riley made is, to a certain extent, met. After all, this is the problem that all of us who are working in experimental neurology are trying to solve; i. e., how can we open the cavity of the brain and the spinal cord and close them again without doing more damage than we intended?

Professor Pike's comments are welcome. I am extremely happy that the problem is one that had suggested itself to him, and I may say that I have taken great inspiration from his papers. They have always been most suggestive, and many of the problems that we are working at came home to us indirectly as a result of his work.

EFFECT OF HYPERVENTILATION ON THE EXCITABILITY OF THE MOTOR CORTEX IN CATS

AN EXPERIMENTAL STUDY

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It has long been known that minor symptoms of hyperexcitability of neuromuscular activity, such as twitchings of the muscles, diminution of the threshold of motor nerves, etc., designated under the syndrome of tetany, result from hyperventilation. In 1924, Rosett,[1] in this country, and, almost simultaneously, Foerster,[2] in Germany, applied this method of investigation to the study of diseases of the central nervous system, especially to epilepsy. This proved to be a successful conception, as both authors were able to show that hyperventilation in epileptic patients may produce marked symptoms of motor and sensory excitation and even true epileptic seizures. Foerster stated that he observed epileptiform seizures in 55 per cent of his patients. Many subsequent investigations confirmed this interesting observation, and the results were at variance only in respect to the percentage of cases in which epileptic seizures followed forced voluntary hyperventilation. Other clinicians have been unable to corroborate the initial statements of Rosett and Foerster.

Not much is known experimentally concerning this phenomenon. There have been a number of investigations on the changes in the blood during and after hyperventilation (Bigwood, Lennox and others), but we are not aware of a systematic study of the excitability of the so-called motor cortex under hyperventilation.

The difficulties with experiments of this nature lie especially in the maintenance of uniform conditions. The anesthesia must be uniform over a long period, and the cortex must be kept under as constant

From the Laboratory of Neurophysiology, Yale University.

1. Rosett, J.: The Experimental Production of Rigidity, of Abnormal Involuntary Movements and of Abnormal States of Consciousness in Man, Brain **47:** 293, 1924.

2. Foerster, O.: Hyperventilationsepilepsie, Zentralbl. f. d. ges. Neurol. u. Psychiat. **38:**289, 1924.

physical conditions as possible, that is, with regard to its temperature and moisture. Furthermore, the temperature of the animal must be maintained constant, notwithstanding the hyperventilation applied. Finally, the electrical stimulation must be constant in strength and duration throughout the actual experiment. We have tried to satisfy all these conditions by certain devices.

EXPERIMENTAL METHODS

The animals (cats) were anesthetized by the intraperitoneal injection of diallyl barbituric acid early in the morning. Although various animals show marked individual differences in susceptibility to this drug, we always started with from 0.5 to 0.55 cc. per kilogram of body weight, giving more of the drug if necessary. This dose usually gives a satisfactory anesthesia for hours, with a fairly excitable cortex. When anesthesia was complete, the animal was fastened on the operating table with an artificial heating device, and the head was fixed rigidly in a special head clamp. A tracheal cannula with a side tube was inserted for later artificial ventilation. The tendon of the tibialis anticus of one side was then connected with the lever of a large Marey tambour, which was connected by a heavy-walled rubber tube with a second tambour, recording on a Palmer kymograph; the recording of time and stimulation was also provided for. The motor cortex of the cerebral hemisphere opposite to the tibialis anticus taken for recording was exposed, although the dura was not opened until the actual experiment was started in the early afternoon. After the dura was opened the cortex was irrigated throughout the whole experiment with warm saline solution, kept at a constant temperature by an immersed electrical heating coil with suitable resistance. The temperature of the saline solution dripping on the cortex was 39 C. The superfluous solution was constantly drained off by cotton pads. This irrigation was interrupted only for from 5 to 10 seconds before each stimulation of the cortex and was started again immediately after cessation of the stimulation. The electrical stimulation was done by means of a Harvard induction coil, connected with a 2 volt storage battery arranged as for delivering single induction shocks. In the primary circuit was a Bernstein interrupter (Zimmermann pattern, with a condensor parallel for the absorption of the opening sparks); its spring was set at 50 vibrations per second. The stimulation was done not by closing the primary circuit but by taking away a short circuit in the secondary circuit. This was done mechanically on a rotating disk, so that all stimulations were of the same strength and duration.[3] In each experiment the optimal duration and strength of the stimulus were determined for a cortical focus on the postcruciate gyrus, which yields a weak contraction of the tibialis anticus of the contralateral hind leg. The stimulations were all done by the

3. The marking of the periods of stimulation on the recording drum was done manually by the closing and opening of an independent signal circuit at the moments of opening and the closing of the short circuit in the secondary circuit. Though it was tried to do this as accurately as possible, still this method occasionally results in small apparent differences of duration of the stimulations in the records (on the fast drum); the actual stimulations, however, throughout each experiment, were all of exactly the same duration. We adopted this method because we did not want to introduce a signal in the primary circuit, as this would probably have interfered with the uniformity of the stimulations.

bipolar method, with the tips of the electrodes from 2 to 3 mm. apart. Mostly, a slightly supraliminal stimulus was used; in a few experiments a stronger stimulus was applied.

The electrical stimulations were repeated every minute. By using this time interval, we obviated the interference of "facilitation" phenomena, i. e., the cumulative effect of stimuli succeeding each other in too rapid sequence.

The artificial ventilation used was of the interrupted type, at 44 strokes per minute; the depth of the blowing up of the lungs was regulated by a clamp on the side arm of the tracheal cannula. In a few of the experiments, the air, before reaching the trachea of the animal, bubbled through warm water at 40 C.

EXPERIMENTS

The experiments are divided into four groups.

Group I.—First, the effect of hyperventilation alone on the excitability of the "motor" cortex was studied. The results of the eight experiments of this series are as follows:

EXPERIMENT 1. (Oct. 7, 1931).—There were "cortical waves" of excitability (we shall refer to this phenomenon in the comment on this series). After fifteen minutes of hyperventilation there was a uniform augmentation of the cortical responses, the waves disappeared. After the hyperventilation was stopped, the responses became smaller again, and the "cortical waves" reappeared.

EXPERIMENT 2 (October 9).—No distinct change in the cortical responses during hyperventilation could be detected.

EXPERIMENT 3 (October 14).—There were "cortical waves." After eleven minutes of hyperventilation, the contractions of the tibialis anticus became definitely stronger and the "waves" disappeared. After cessation of the hyperventilation, the responses returned to their original size.

EXPERIMENT 4 (October 15).—No obvious changes in the cortical responses were observed during hyperventilation.

EXPERIMENT 5 (October 16).—Before hyperventilation, "waves" in the cortical excitability were observed. Definite augmentation of the cortical responses and disappearance of the "waves" occurred during hyperventilation. After cessation of the hyperventilation, the excitability of the cortex diminished again and the "waves" reappeared in their original intensity.

EXPERIMENT 6 (October 19).—After twenty-three minutes of hyperventilation, the cortical responses were markedly larger and an epileptiform after-discharge occurred. After cessation of the forced ventilation, the excitability of the cortex was depressed for four minutes, after which the responses gradually returned to the intensity they showed before the hyperventilation. Subsequently, hyperventilation was started again and after five minutes resulted in marked augmentation of the cortical responses with clonic after-discharge and even a spread of response to the fore limb of the same side. After cessation of this period of hyperventilation, the same observation could be made as after the first period of hyperventilation, i. e., an initial depression of the cortical excitability lasting about five minutes and then a gradual return to normal.

EXPERIMENT 7 (November 4).—Before the hyperventilation, there were "cortical waves" of excitability. Hyperventilation was applied twice in this experiment, at an interval of one hour. During both periods of forced ventilation, an aug-

mentation of the cortical responses and a disappearance of the "waves" were observed, in the first instance after seven minutes of hyperventilation and in the second after three minutes.

EXPERIMENT 8 (November 5).—There were "cortical waves" before the hyperventilation. No conclusive evidence of augmentation of the cortical responses during prolonged hyperventilation could be observed.

Comment.—In five of the eight experiments of this series a definite augmentation of the excitability of the cortex under hyperventilation was observed; in three animals no such augmentation could be detected.

Of interest, furthermore, is the fact that in spite of our strict experimental conditions, the excitability of the cerebral cortex, before hyperventilation, showed itself not to be perfectly steady, but rather oscillating in a wavelike manner. The span of these waves of cortical excitability varied in the experiments of this series and in the "normal" periods of those of the other groups between from three to five minutes. Occasionally we found that the "period" of such a wave was only two minutes. As in these experiments we used an interval of one minute, we cannot say whether the period of these waves might even be shorter than two minutes; this would be an interesting problem to investigate, but the difficulty with shorter intervals between the stimulations would be that one would risk the interference of "facilitation" phenomena.

During hyperventilation these "waves" disappeared in the five experiments in which the results were positive, and the cortical responses became uniformly larger than the largest of the responses under the conditions of normal respiration. This disappearance of the cortical waves may be interpreted also, we think, as a symptom of the augmentation of cortical excitability in these five experiments under hyperventilation.

Because a certain number of the animals were apparently refractive to hyperventilation, so far as the excitability of the cerebral cortex is concerned, it was considered of interest to investigate the influence of combining the hyperventilation with a factor that in itself raises the excitability of the central nervous system, namely, the injection of a dose of strychnine so small that it does not result in strychnine spasms but only in a state of slight hyperreflexia. It is known from experiments by Sherrington and by Magnus that a dose of 0.1 mg. of strychnine per kilogram of body weight gives this stage of strychninization.

Group II.—In a second series of twelve experiments, after beginning each experiment with the determination of a suitable cortical stimulation, we injected into each animal 0.1 mg. of strychnine sulphate per kilogram of body weight and started hyperventilation after an interval varying from twenty to thirty minutes. In a few experiments we started the cortical stimulations only a few hours after the injection

of strychnine; in these experiments the hyperventilation was initiated after a stimulus of suitable strength and duration had been found.

The results of these twelve experiments are briefly as follows:

EXPERIMENT 9 (November 6).—During hyperventilation there was definite augmentation and shortening of the latency of the motor responses, epileptiform after-discharge in the tibialis anticus and spread of response to the fore limb. There was a disappearance of the cortical "waves" during forced ventilation, which reappeared after cessation of the hyperventilation. This was followed by an initial depression of the cortical excitability for about five minutes.

EXPERIMENT 10 (November 7).—The results were similar to those of experiment 9.

EXPERIMENT 11 (November 10).—The results were similar to those of experiment 9 (fig. 1).

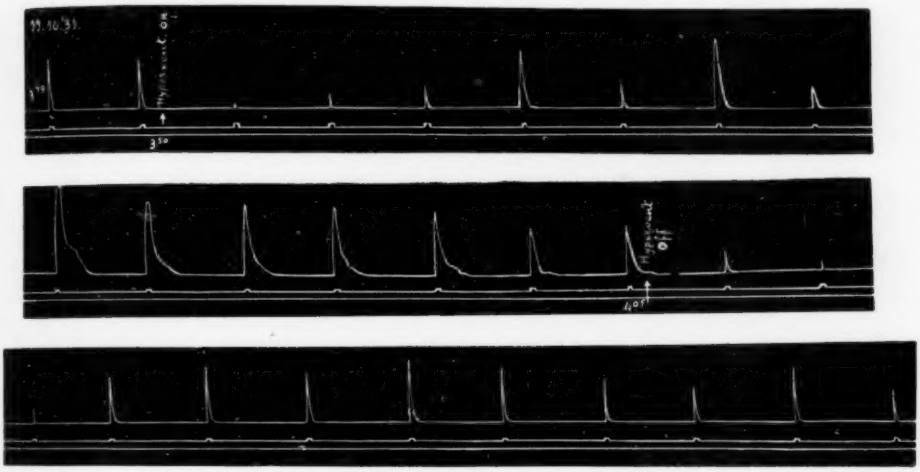

Fig. 1.—Experiment of Nov. 10, 1931. Male cat. Diallyl barbituric acid anesthesia. One-tenth milligram of strychnine per kilogram given intraperitoneally at 2:25 p. m. Distance of coil in all stimulations, 7.5 cm.; duration of each stimulation, two seconds; intervals, one minute.

EXPERIMENT 12 (November 11).—The same animal was used as in experiment 11 on the previous day. Although the anesthesia was still fairly deep from the diallyl barbituric acid given on the previous day, 0.25 cc. of diallyl barbituric acid was injected intraperitoneally at 10 a. m., as the animal showed slight "voluntary" movements. The weight of the cat was 1.95 Kg. The stimulations were started with the coil at 8 cm. An intraperitoneal injection of 0.2 mg. of strychnine was given at 10:11. At 10:24 a. m. the distance of the coil was increased to 8.5 cm., as there was a slight augmentation of the motor response after the strychnine, but without any alteration in latency or any sign of after-discharge. With this strength of stimulation, the responses were of the same size as before the strychninization. At 10:32 a. m., hyperventilation was applied. After thirteen minutes of hyperventilation, there appeared a strong increase in the motor responses, with a marked decrease in latency, a clonic after-discharge in the

tibialis anticus and a spread of response to the muscles of the fore limb of the same side.

The cortical "waves" still present after the injection of strychnine disappeared during the hyperventilation, to return again after its cessation. At 11 a. m., the hyperventilation was applied once more and augmentation similar to that observed during the first period of hyperventilation occurred again; the clonic after-discharge, however, was not present (fig. 2).

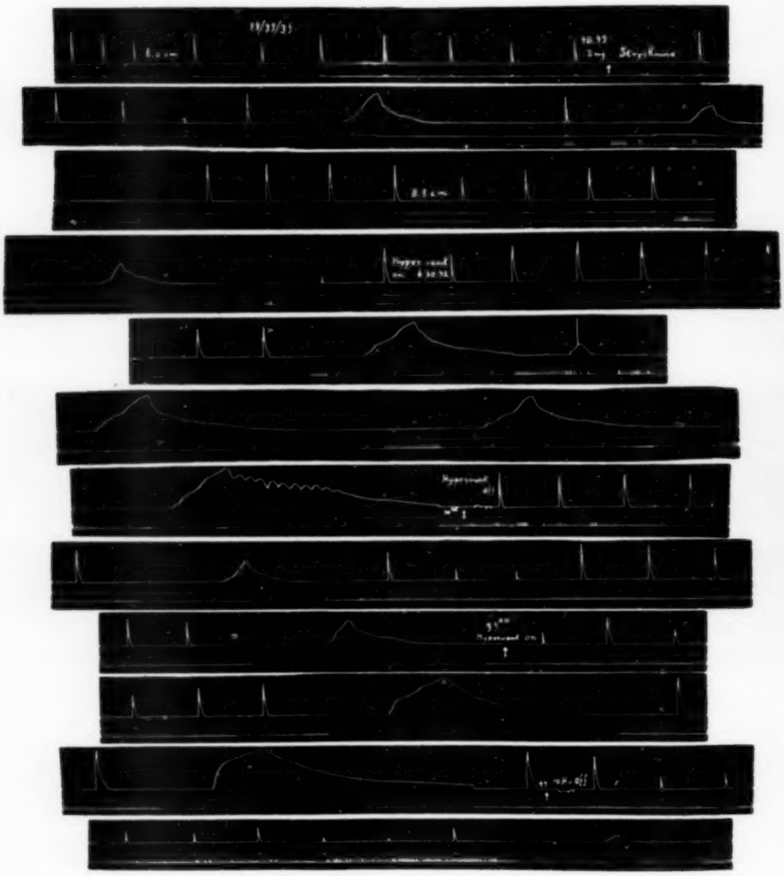

Fig. 2.—Experiment of Nov. 11, 1931. First stimulations with coil at 8 cm. At 10:11 a. m., 0.2. mg. of strychnine injected. At 10:24 a. m., strength of the stimulus reduced to a coil distance of 8.5 cm. Hyperventilation started at 10:32 a. m. Waves present before hyperventilation disappeared. After cessation of hyperventilation at 10:45 a. m., responses became smaller again and the "waves" reappeared. Hyperventilation was started once more at 11:00 a. m. Again augmentation of the cortical responses occurred, with marked shortening of the latent period. No clonic after-discharge.

In the afternoon the experiment was repeated once more on this animal. The vagi had been cut in the neck at 11:30 a. m. At 2:46 p. m., 0.2 mg. of

strychnine was injected again intraperitoneally. At 3 p. m., the response to cortical stimulation was markedly increased, so that even an after-discharge occurred. The latency of the responses was, however, not shortened. During hyperventilation, started at 3:40 p. m., there was distinct intensification of the cortical responses, and at 3:46 a generalized convulsion appeared coincidental with a stimulation. The latency of the responses was much shorter than before hyperventilation; apparently the effect of the strychnine injected in the morning had not yet abated (fig. 3).

Experiment 13 (November 16).—During hyperventilation there was augmentation of responses, an epileptiform after-discharge and a spread to the ipsolateral fore limb. Cortical waves were noted before and after hyperventilation; they were absent during the hyperventilation.

Experiment 14 (November 20).—This experiment shows that the augmentation of cortical excitability can be demonstrated to appear also with far supraliminal stimuli.

Part 1: Augmentation of the motor response was only slight, although there was a clonic after-discharge, and also a distinct spread to the fore limb during hyperventilation.

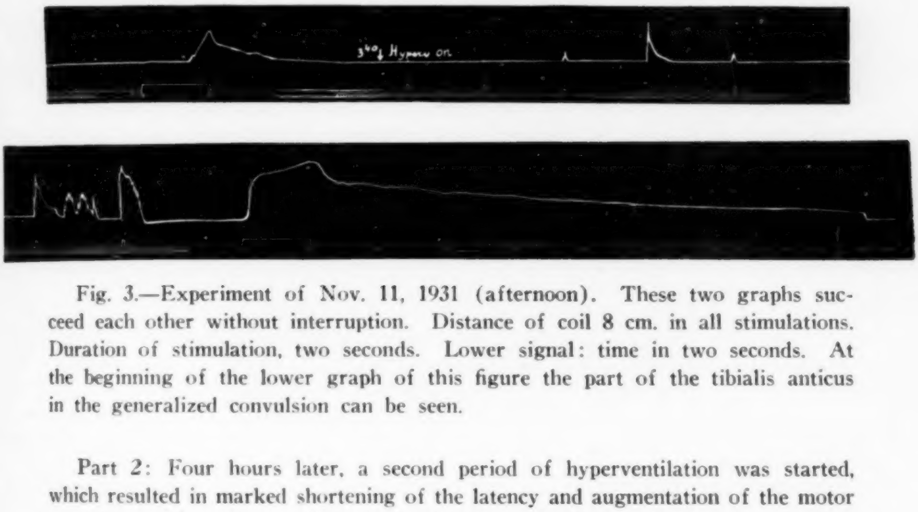

Fig. 3.—Experiment of Nov. 11, 1931 (afternoon). These two graphs succeed each other without interruption. Distance of coil 8 cm. in all stimulations. Duration of stimulation, two seconds. Lower signal: time in two seconds. At the beginning of the lower graph of this figure the part of the tibialis anticus in the generalized convulsion can be seen.

Part 2: Four hours later, a second period of hyperventilation was started, which resulted in marked shortening of the latency and augmentation of the motor responses. After the stopping of the forced ventilation, the responses were much less vigorous, although the hyperreflexia due to the strychninization (strychnine injected eight hours previously) was still obvious (fig. 4).

Experiment 15 (November 24).—First, a bilateral pneumothorax was induced, and the animal was maintained on artificial respiration of normal frequency and amplitude. After injection of the usual dose of strychnine there were no changes. Hyperventilation produced augmentation of motor response, spread of response and shortening of latency.

Experiment 16 (November 28).—After the injection of strychnine there were no changes. During forced ventilation there was marked spread in the motor response; the cortical waves were still present.

Experiment 17 (November 20).—Augmentation of motor response and marked spread were the outstanding positive effects during hyperventilation.

Experiment 18 (December 1).—Augmentation of motor response occurred during hyperventilation; there were also shortening of the latency (not recorded on the graph) and spread of response. The responses became small again after cessation of the forced respiration, although the strychnine hyperreflexia was of the same intensity as during the forced ventilation (fig. 5).

Experiment 19 (December 2).—Augmentation of motor response, epileptiform after-discharge in the tibialis anticus and marked spread of response occurred during the period of hyperventilation.

Experiment 20 (December 6).—Part 1: Strychnine was not injected. No positive change occurred during forced ventilation.

Part 2: Strychnine was injected. There were considerable augmentation of motor response and spread to the ipsolateral fore limb only during hyperventilation.

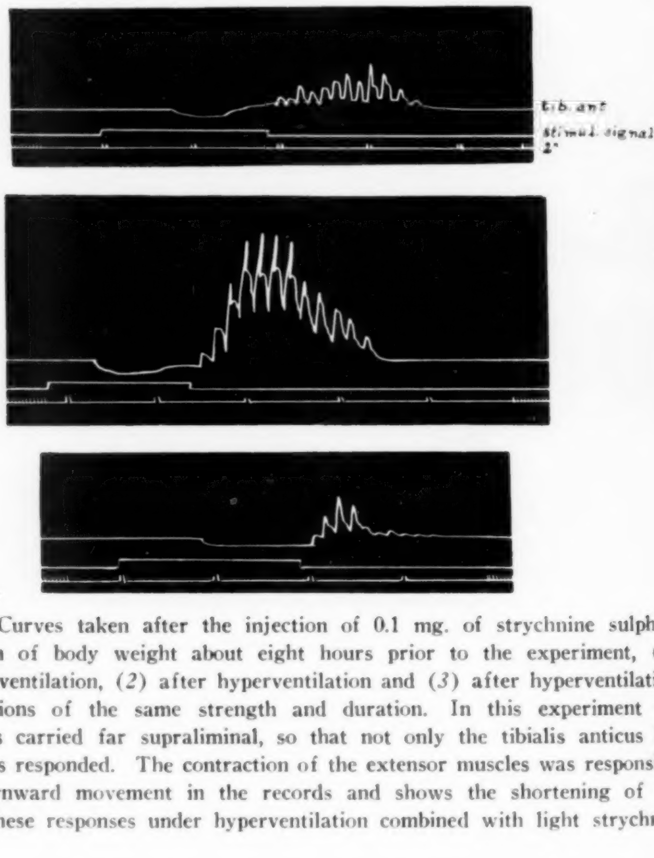

Fig. 4.—Curves taken after the injection of 0.1 mg. of strychnine sulphate per kilogram of body weight about eight hours prior to the experiment, (*1*) before hyperventilation, (*2*) after hyperventilation and (*3*) after hyperventilation. All stimulations of the same strength and duration. In this experiment the stimulus was carried far supraliminal, so that not only the tibialis anticus but other muscles responded. The contraction of the extensor muscles was responsible for the downward movement in the records and shows the shortening of the latency of these responses under hyperventilation combined with light strychninization.

Comment.—Group II is a series of twelve experiments on cats that had received a small nonconvulsant dose of strychnine before hyperventilation was started. With the exception of one animal (experiment 12, part 1), this dose of strychnine in itself produced no obvious

changes in the excitability of the cortex, though in all the cats distinct hyperreflexia (spinal) was present. In this one instance, although there were a slight augmentation of the motor response and a slight after-discharge, there was no spread of the motor discharge. During hyperventilation in one animal (experiment 12, part 2) an epileptiform seizure was noted coincident with the termination of a stimulus, probably, as already stated, because of a cumulative action from the first dose of strychnine injected in the morning. In the strychninized animals, hyperventilation produced in every case an augmentation of the cortical responses and a spread of response to other parts of the body, combined, in almost all animals, with epileptiform after-discharge and a shortening of the latent periods. The fact that this augmentation of responses occurred after section of both vagi (experiment 12, part 2)

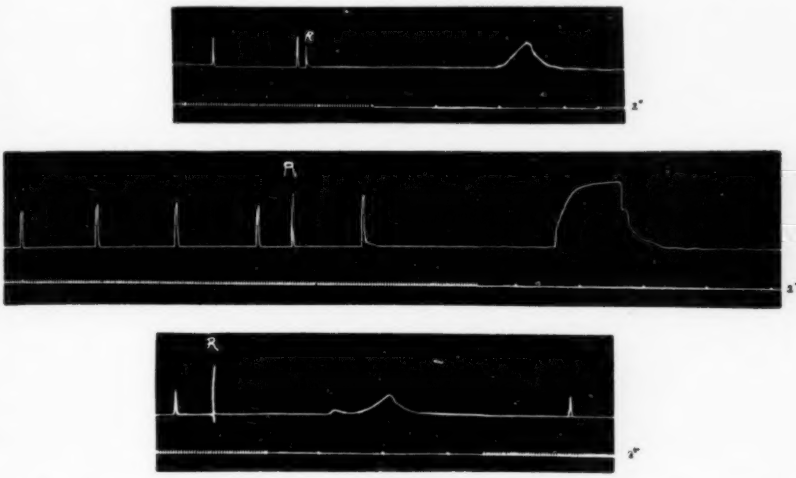

Fig. 5.—Curves taken after the injection of 0.1 mg of strychnine sulphate per kilogram at 9:35 a. m. *A*, before hyperventilation; indicates hyperreflexia on gentle tapping of the back of the animal. *B*, hyperventilation begun at 10:14 a. m.; last response (on fast drum) at 10:24 a. m. *C*, hyperventilation stopped at 10:26 a. m.; last response (on fast drum) at 10:35 a. m. All stimulations with same strength (coil at 8.8 cm.).

indicates that stimuli arising in the lungs do not play a rôle in the production of the hyperexcitability. The experiment in which a bilateral pneumothorax was induced (experiment 15) was done to determine whether the augmentation of responses might have been due to a better contact of the electrodes against the cortex during hyperventilation, as the respiratory excursions of the brain during this procedure are often somewhat larger. The respiratory movements of the brain under normal respiration, and even during hyperventilation in the animal

under diallyl barbituric acid anesthesia, are mostly much less than under other anesthetics, especially ether. The volume of the brain in animals under diallyl barbituric acid anesthesia is mostly definitely shrunken. The fact that with a bilateral pneumothorax, after which there are no more appreciable respiratory movements of the brain, the augmentation still occurs, indicates that the factor already mentioned does not enter into consideration.

Since hyperventilation, produced by blowing off carbon dioxide from the body, eventuates in alkalosis, we investigated, in a few animals, the influence of an injection of sodium bicarbonate on the excitability of the cortex. Ordinarily, such an injection of alkali is followed by a depression of respiration, which represents an attempt of the body to counteract the changes in acid-base equilibrium by a retention of carbon dioxide. To combat this physiologic hypoventilation, the animals were subjected in these experiments to artificial respiration of normal frequency and depth.

Group III.—After a period of normal artificial respiration, long enough to establish a constant cortical excitability and prior to the injection of the sodium bicarbonate, the animals received an injection of 0.1 mg. of strychnine per kilogram of body weight. Then, after a suitable interval, when hyperreflexia was present, from 8 to 10 gm. of sodium bicarbonate in Ringer's solution, saturated at body temperature, was injected intraperitoneally.

The results of the experiments in group III are, briefly, as follows:

Experiment 21 (December 2).—11 a. m.: Five tenths cubic centimeters of diallyl barbituric acid per kilogram was given intraperitoneally.

December 3.—2 p. m.: Cortical stimulations were started. 2:40 p. m.: Normal artificial respiration was started. 2:45 p. m.: One tenth milligram of strychnine sulphate per kilogram was given intraperitoneally. There was no change in the cortical response. 3:16 p. m.: Eight grams of sodium bicarbonate in saturated solution was injected intraperitoneally. This gave rise, aften ten minutes, to a definite augmentation of the motor responses, with clonic after-discharge and spread to other limbs. At 3:55 p. m. generalized convulsive movements were noted in all four extremities and in the muscles of the neck and trunk, coincident with the termination of a stimulus. 4:17 p. m.: The augmentatory effects had passed, although the hyperreflexia produced by strychnine was still marked.

Experiment 22 (December 4).—Strychnine and sodium bicarbonate were given as already described. After injection of the sodium bicarbonate a distinct augmentation of the motor response appeared, with pronounced after-discharge and a slight spread of response.

Experiment 23 (December 5).—To test whether sodium bicarbonate alone might produce an augmentation of response, we first injected it without strychnine, and when after a long period, this injection was not followed by appreciable changes in the cortical excitability, we injected the usual dose of strychnine, followed by a second injection of sodium bicarbonate. Neither injection of sodium bicarbonate was followed by a distinct augmentation.

Comment.—These three experiments suggest that it is probable that sodium bicarbonate and strychnine give rise to the same augmentation of cortical excitability as does hyperventilation plus strychnine, but the present number of experiments is too small to warrant a more definite statement. We wish to reserve a definite opinion on this part of the work until further experimentation has been done, together with an investigation of the chemical changes going on in the body after hyperventilation or injection of sodium bicarbonate. In experiment 23, the double dose of sodium bicarbonate may have been responsible for the inconclusive results.

Group IV.—Finally, a few experiments were done with local application of strychnine to the motor cortex under the electrodes. In the former experiments with the injection of strychnine, of course, the greatest part of the central nervous system, at least its lower functional levels, was in a state of hyperactivity. It was thought interesting to investigate the influence of hyperventilation when the cerebral cortex near the locus of stimulation alone was strychninized. In these experiments we could not use our method of constant irrigation of the cortex, but we packed the opening in the skull and dura with warm, moist cotton, covered this with a piece of rubber dam, through a hole in which passed the electrodes, and covered the rubber dam with a thick pad of dry cotton. The edges of the rubber dam were kept tight against the underlying moist pads of cotton by a ring of moist cotton pads. In this way a small, closed, cone-shaped room was built just above the opening in the skull, and we believe that it is permissible to assume that by this device in these experiments the cortex was kept at an even temperature and degree of moisture.

The result of this series was that in all of the animals augmentation of cortical excitability during hyperventilation could be observed similar to that occurring after general strychninization. In some of these experiments the local application of strychnine to the part of the motor cortex under investigation was followed by a slight augmentation of the cortical excitability, which was much smaller than the augmentation during hyperventilation. Furthermore, the local strychninization was not followed by after-discharge and spread of response, and resulted in only slight, if any, shortening of the latent period (fig. 6).

This series shows that apparently the local strychninization of the cerebral cortex, together with hyperventilation, is sufficient to bring forth consistently a marked augmentation of cortical excitability with shortening of latency, after-discharge and spread of response to other parts of the body, and that to produce this effect the mild strychninization of other levels of the central nervous system, as in the experiments of the preceding series, is irrelevant.

GENERAL COMMENT

These experimental investigations show that hyperventilation alone in a number of cases (62.5 per cent), though certainly not in all, gives rise to a distinct augmentation of the excitability of the cerebral cortex.

This rise in excitability of the cortex shows itself in an increase of the motor response, although the stimulus remained constant, and in a

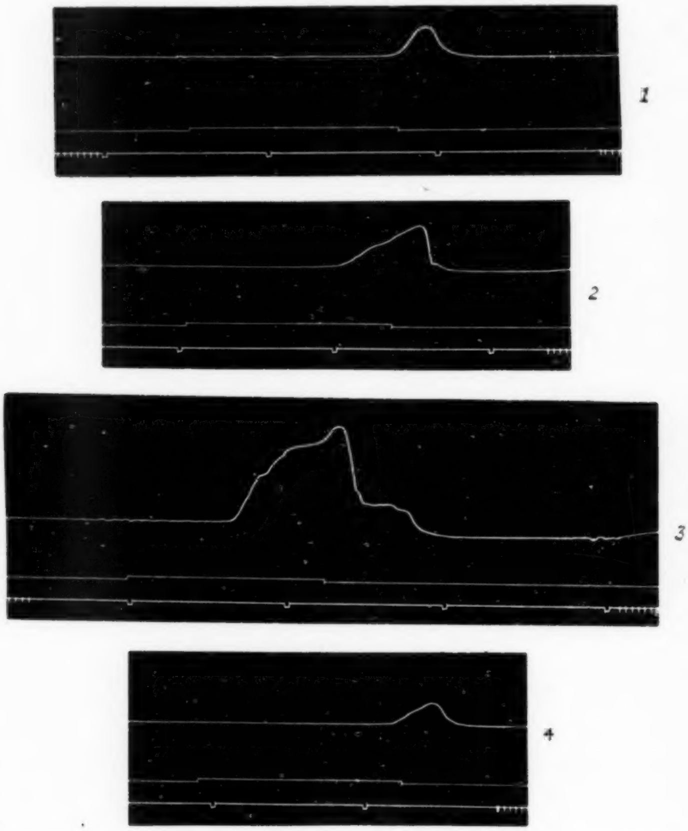

Fig. 6.—Curve 1, before hyperventilation and before application of strychnine. Curve 2, eight minutes after local strychninization of motor cortex. Curve 3, six minutes after the beginning of hyperventilation. Curve 4, eighteen minutes after the cessation of hyperventilation. In all the records the upper signal indicates stimulation, and the lower signal marks time in two seconds.

disappearance of the "waves" of cortical excitability that are normally present. In only one other experiment did the latency of the cortical response become smaller, and an epileptoid after-discharge and spread of response to muscles of other parts of the body occur.

This shows, in confirmation of the conclusion reached through clinical investigations on hyperventilation in epileptic persons, that the alkalosis resulting from hyperventilation cannot be the only factor in the production of epileptic seizures through hyperventilation. If, however, the excitability of the central nervous system is raised by the injection of a small dose of strychnine, which in itself does not obviously affect the cortical excitability (in one case in twelve in our series), the augmentation of cortical excitability by hyperventilation is much more marked, expressing itself then not only in a larger cortical response but in marked shortening of the latency of the responses, after-discharges and a spread of response to muscles of other parts of the body. This result was observed in all our experiments (100 per cent of the cases).

This result is in line with the conclusion drawn by some clinicians that in the elicitation of epileptoid discharges through hyperventilation another factor plays a rôle, which is designated occasionally as a "tendency to fits" (*Krampfbereitschaft* of German authors). Of course, this denomination only shows our ignorance with regard to the second factor; furthermore, it is difficult to understand why the readiness to motor discharges should be absent in one epileptic patient and present in another. It must be realized that in these experiments there are at least three factors: electrical stimulation, hyperventilation and strychninization. Hyperventilation and strychnine, in the dose given in these experiments, without electrical stimulation do not produce, at least in cats, any symptom of motor excitation.

The same strong augmentation of cortical excitability can be observed if hyperventilation is combined with local strychninization of the cerebral cortex at and immediately around the locus of cortical stimulation.

The amount of strychnine applied to the cortex in these experiments was extremely small; it may be estimated at about from 0.005 to 0.02 mg., and certainly did not reach levels and parts of the cortex other than the few square millimeters to which it was directly applied.

This result means that the hyperactivity of the cortex, induced by this minute local strychninization, together with the chemical changes in the body through hyperventilation, is sufficient to produce marked epileptoid discharges on liminal cortical stimulation.

A few words may be added about the "waves" of cortical excitability.

We think that the external conditions under which the cortex was kept in these experiments may be looked on as fairly constant. If this is true, the waves of cortical excitability are an interesting phenomenon, for we may look on them as the expression of intrinsic rhythmic changes in the functional activity of the cortex.

It is interesting in this respect to draw attention to the fact that, in the psychologic field, fluctuation in mental activities (attention, perception of slight differences in visual and auditory stimuli, especially when of threshold intensity) is well known. Without going so far as to identify the two phenomena, we cannot help feeling that perhaps to some extent they are analogous, although there are differences.

The frequency of the waves of apperception and attention is reported by psychologists to be of a few seconds, whereas our waves of cortical excitability showed a period of from two to five minutes. Figure 7 gives another illustration of the occurrence of these waves. It must be remembered that these waves, in our experiments, were observed in deeply anesthetized animals. It is plausible to suppose that this factor might result in a lengthening of normally much shorter fluctuations in cortical activity. The functional level of these two phenomena, although in both cases cortical, is probably different. Furthermore, we timed our stimulations, as already stated, at one minute intervals in order to be safe from facilitation phenomena. It might be that with closer

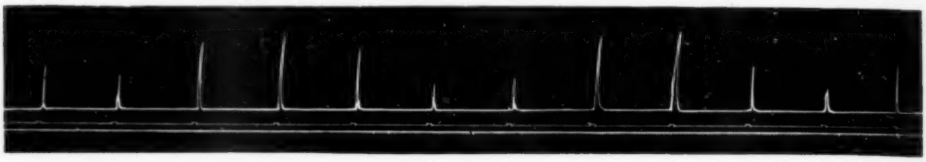

Fig. 7.—Waves in excitability of cortex under constant experimental conditions. Stimuli of the same strength and duration; uniform conditions in cortex and animal.

spaced stimulations these waves would show a shorter period. That is, however, a matter for further investigation. The waves were also found to be present in experiments on cortical excitability under uniform conditions in the monkey (experiments of Dusser de Barenne with Dr. Clyde Marshall).

How these fluctuations in the fundamental activities of the cortex are brought about can as yet be only a matter of speculation. It may be, for instance, that they arise from the conflict and an unsteady balance between excitatory and inhibitory effects in the cortex. But only further experimentation can throw light on this point.

SUMMARY

This paper presents the results of an investigation of the excitability of the cerebral cortex in the cat before, during and after hyperventilation, under uniform experimental conditions. The results obtained are as follows:

1. Hyperventilation alone results, in 62 per cent of the cases, in a slight augmentation of the cortical responses; in 38 per cent the excitability does not change.

2. After the injection of a small nonconvulsant dose of strychnine (0.1 mg. per kilogram of body weight) the effect of hyperventilation is much more marked, as not only is the augmentation of the cortical responses greater, but there appear shortening of the latency, epileptoid after-discharges and spread to muscle groups in other parts of the body. This strong augmentation is a constant phenomenon, and occurs even with liminal stimuli.

3. The same augmentation is constantly observed when hyperventilation is combined with local strychninization of a small area of the cortex at and immediately around the focus of cortical stimulation.

4. Although the experimental conditions in these experiments may be looked on as constant (depth of anesthesia, conditions of the cortex, temperature of the animal and strength and duration of electrical stimulation) the excitability of the cortex shows slight "wavelike" fluctuations. These waves are looked on as the expression of intrinsic fluctuations of cortical activity.

5. Under hyperventilation these "waves" disappear.

6. After cessation of the hyperventilation, the excitability of the cortex is almost constantly depressed for the first four or five minutes, after which it returns to normal values.

RELATION OF MODIFICATIONS OF MUSCLE TONUS TO INTERRUPTION OF CERTAIN ANATOMIC PATHWAYS

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Methods of measuring the tension, contractility, elasticity, extensibility, ductility, resiliency, plasticity, viscosity and hardness of muscle have aimed to give a simple numerical value to tonus which is found to be a complex property of muscle.

It is needless for our purpose to review the large literature on the various methods of measuring the several parts of muscle tonus in animals or in man, nor does it further our end to attempt to correlate our findings with the conclusions reached by other investigators dealing with research of properties other than those we have examined.

We propose to describe some methods of examining a certain property of muscle comparable to viscosity in the cat's muscles at rest, when tetanized and under conditions of various reflex activities, to note the results of these examinations and to compare them with the results of examination of muscles in man suffering from various diseases.

The difficulty of formulating a definition of muscle tone may be realized when we note that the term viscosity itself retains several meanings. Maxwell [1] stated that when a stress, if maintained constantly, causes a strain or displacement which increases continually with time, the substance is said to be viscous. Bingham [2] pointed out that the distinction between fluids and solids is not always sharply drawn, and that much labor has been ill spent in the attempt to measure the viscosity of solids on the assumption that solids are only very viscous liquids and, therefore, that plasticity and the fluidity of solids

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Read at the International Neurological Congress, Bern, Switzerland, Sept. 2, 1931.

1. Maxwell, J. Clerk: Theory of Heat, New York, Longmans, Green & Company, 1897.

2. Bingham, E. C.: Fluidity and Plasticity, New York, McGraw-Hill Book Company, Inc., 1922.

are synonymous terms. Whereas Maxwell stated that "What is required to alter the form of a soft solid is sufficient force, and this when applied produces its effect at once," Bingham said that this is of course only relatively true, because plastic deformation is a function of time. Lord Kelvin,[3] noting that the logarithmic decrement of the vibrations is greater in lead and zinc than it is in steel, reasoned as follows: "Hence there is in elastic solids a molecular friction which may be properly called viscosity of solids, because as being an internal resistance to change of shape depending on the rapidity of the change, it must be classed with fluid molecular friction, which by general consent is called viscosity of fluids." He further stated: "But at the same time it ought to be remembered that the word viscosity as used hitherto by the best writers, when solids or heterogenous semisolid, semifluid masses are referred to, has not been distinctly applied to molecular friction, especially not to molecular friction of a highly elastic solid within its limits of high elasticity, but has rather been employed to designate a property of slow, continual yielding through a very great or altogether unlimited extent of change of shape, under the action of continued stress." Bingham rightly called attention to the danger of confusion of terms, and proposed that the term "viscosity of solids" was unnecessary, and that its meaning should be supplanted by the internal friction and mobility of solids.

Bingham defined plasticity as a property of solids in virtue of which they hold their shape permanently under the action of small, shearing stresses, but that they are readily deformed, worked or molded under somewhat larger stresses. It is a complex property, made up of two independent factors, internal friction and mobility. The after-lengthening of a stretched muscle, which Blix[4] interpreted to mean that a muscle was a viscous-elastic body, would correspond to Bingham's internal friction and mobility, or plasticity, and to Maxwell's viscosity. Langelaan[5] stated that a body is said to be plastic if its form is permanently altered when a stress to which it is subjected is removed. This corresponds to Maxwell's definition: "If the form of the body is found to be permanently altered when the stress exceeds a certain value the body is said to be soft or plastic." Langelaan was considering that deformation which resulted from slow yielding to a continuous stress, and in this respect he was considering what Maxwell defined as viscosity. Now it is apparent that plasticity and viscosity are not synonymous or interchangeable, nor is the one reciprocal to the

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3. Lord Kelvin (Thompson, W.), quoted by Bingham (footnote 2).

4. Blix, M.: Die Länge und die Spannung des Muskels, Skandinav. Arch. f. Physiol. **4**:399, 1893.

5. Langelaan, J. W.: On Muscle Tonus, Brain **37**:235, 1915.

other. As Maxwell has shown, a body such as a tallow candle is much softer (plastic) than a stick of sealing wax, but if the candle and stick of sealing wax are laid horizontally between two supports, the sealing wax will in a few weeks in summer bend with its own weight, while the candle remains straight. Again, "A block of pitch may be so hard that you cannot make a dent in it by striking it with your knuckles, yet it will in the course of time flatten itself out by its own weight and glide down hill like a stream of water."

Ranson,[6] realizing the confusion that might result from using the term plasticity in its physical sense, and also in the sense with which it is applied to the state of a muscle in the decerebrate animal and to other types of tonus, substituted the word ductility, meaning thereby the tendency to undergo permanent elongation when subjected to prolonged longitudinal stress. This term, however, is not synonymous with viscosity when dealing with solids.

Gasser and Hill[7] found, among other things, that if when a muscle was stimulated with a tetanizing current and its tension recorded it was allowed suddenly to shorten freely a given small distance, the tension fell to or toward zero and then slowly rose again. They concluded that this indicated that the phenomenon in question was due in some way to the viscosity of the substance of the active muscle. Hill[8] said, "It is possible that we are not correct in ascribing all these curious effects to viscosity. At present, however, we can only say that if it be not viscosity, it is something which behaves in a remarkably similar way." Later, he[9] said:

> The extreme differences, however, which exist between different muscles, in respect to the speed at which they can shorten and do work, made one doubtful whether simple viscosity was involved. There are many physico-chemical effects which show an equal dependence upon speed. . . . The speed of gelation of a protein, involving the arrangement of its molecules in some kind of regular order, may be slow and largely altered by minute changes in its chemical constitution. In some such way, rather than by invoking simple physical viscosity, one must probably proceed. Viscosity in a sense it is: not gross, but molecular. . . . This slowness of attainment of a final state, involving molecular "viscosity," is a common property of many physico-chemical systems. If such a system be employed for doing mechanical work this hysteresis will manifest itself as ordinary "viscosity."

6. Ranson, S. W.: The Elasticity and Ductility of Skeletal Muscle, Am. J. Physiol. **86**:302, 1928.

7. Gasser, H. S., and Hill, A. V.: The Dynamics of Muscular Contraction, Proc. Roy. Soc., London, s.B **96**:398, 1924-1925.

8. Hill, A. V.: Muscular Activity, Baltimore, Williams & Wilkins Company, 1926.

9. Hill, A. V.: Muscular Movement in Man, New York, McGraw-Hill Book Company, Inc., 1927.

Gasser and Hill have shown that a comparison of the resting with the excited muscle indicates that contracted muscle is not only viscous but is much more so than resting muscle. This work has been corroborated by Levin and Wyman,[10] Winton [11] and Bouckaert, Capellen and de Blende.[12] This observation indicates the possibility of change in the physical properties of muscles under varying conditions. It seems conceivable that when the purpose of function is a rapidly repeated small movement, the organism can utilize a substance quite different in properties from that needed when a sustained, severe stress is required.

We [13] formerly found that if a muscle intoned by a tonic labyrinthine reflex was subjected to a stretch by gradually increasing force, and if the stretch was then released by gradually diminishing the force, the lengthening of the muscle continued beyond the height of the mechanical extension; in fact, the muscle began to shorten only when a small fraction of the maximum force had been reached. Often the muscle shortened very little, and frequently not at all. Obviously, this was a record of a "lengthening reaction." It was found, however, that section of the posterior roots did not modify this lengthening reaction, and from the facts already cited and other observations it was thought that the muscle when intoned by a tonic labyrinthine reflex underwent a physical change not related in any way to a stretch reflex or inhibition; the physical change resembled one in which an elastic substance like rubber was transformed into one like gum. In other words, it became plastic in the sense of Maxwell's definition. At a later date we [14] reported an experiment in which the muscle so intoned was progressively compressed, and when the compression was removed it remained indented whether the posterior roots supplying the extremity were intact or severed, and we believed that further proof was adduced that in certain reflex activities the physical properties of a muscle underwent a change.

For the purpose of this communication we have studied the physical properties of muscles of intact animals at rest; we have also studied tetanized, denervated muscles, deafferented muscles, muscles of decerebrated animals, and of decerebrated animals with labyrinths destroyed,

10. Levin, A., and Wyman, S.: Viscous-Elastic Properties of Muscle, Proc. Roy. Soc., London, s.B. **101**:218, 1927.

11. Winton, F. R.: Tonus in Mammalian Unstriated Muscle, J. Physiol. **69**:393, 1930.

12. Bouckaert, J. P.; Capellen, L., and de Blende, J.: The Visco-Elastic Properties of Frogs' Muscles, J. Physiol. **69**:473, 1930.

13. Pollock, L. J., and Davis, L.: Muscle Tone; Extensibility of Muscles in Decerebrate Rigidity, Arch. Neurol. & Psychiat. **21**:19 (Jan.) 1929.

14. Davis, L., and Pollock, L. J.: Studies in Muscle Tone: Resiliency of Muscles in Decerebrate Rigidity, Am. J. Physiol. **89**:395, 1929.

with completely deafferented upper extremities and with the spinal cord severed below the lower level of deafferentation, and of spinal animals, also muscles in rigor mortis. We have studied muscles in normal man and those in patients with parkinsonism, corticospinal lesions, myotonia atrophica and other diseases.

Although other factors were studied, this communication deals with a study of so-called viscosity in the sense of internal friction and of the viscous-elastic flow. The former is related to the lag, slowing or hysteresis of movement and the latter to so-called ductility or plasticity.

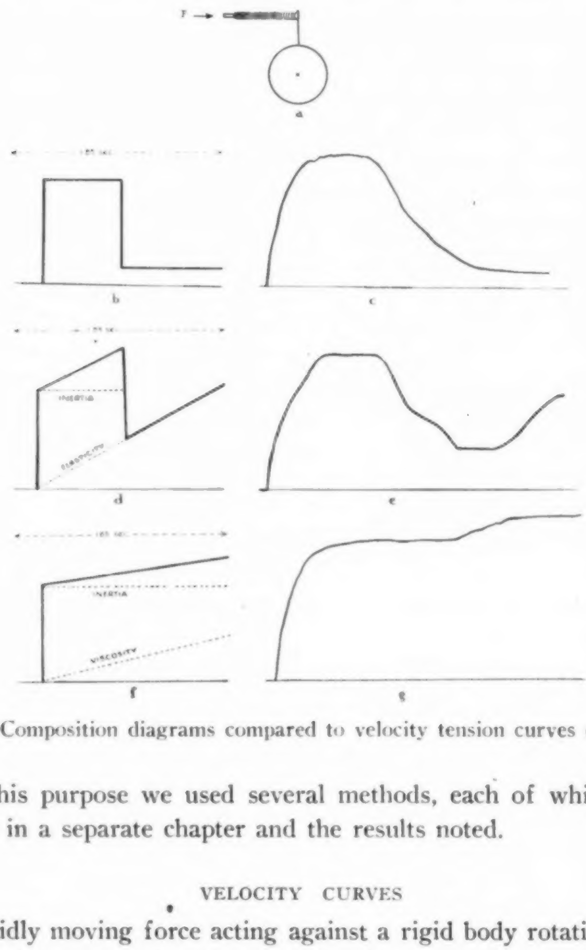


Fig. 1.—Composition diagrams compared to velocity tension curves of models.

For this purpose we used several methods, each of which will be described in a separate chapter and the results noted.

VELOCITY CURVES

A rapidly moving force acting against a rigid body rotating about a fixed axis by means of an interposed spring must overcome mass and inertia, since velocity is being imparted (fig. 1*a*). If the tension of the spring is recorded, it will be found that there will be a more or less immediate rise in tension until movement occurs, which will then

be sustained until the moment of greatest velocity, when the velocities of the movable body and the moving force are equal, and then it will rapidly fall toward zero. Diagrammatically, such a curve may be represented as in figure 1*b*. This diagrammatic representation is roughly approximated by a tracing of a weight being moved by the apparatus used in our experiments (fig. 1*c*). If now the movement of the rotating body is opposed by the resisting force of a spring or other elastic body, the tension curve will be a composition of the inertia curve and that of a spring. This may be represented diagrammatically as in figure 1*d*. A tracing of a weight on the arm board of our apparatus, the movement of which is resisted by a spiral spring, again roughly approximated the curve in figure 1*e*. If, however, the resisting force consists of a so-called viscous body, the tension curve will be a composite of inertia and viscosity. Because of the internal friction, the moment of equal velocity may occur slowly or may never be reached within the limit of movement. As the force of viscosity increases with velocity, the curve may be roughly illustrated as in figure 1*f*. A tracing of a weight resting on the arm board the movement of which is opposed by a thin-walled rubber tubing filled with Chatterton's mixture or with pitch shows a curve roughly approximating that in figure 1*g*.

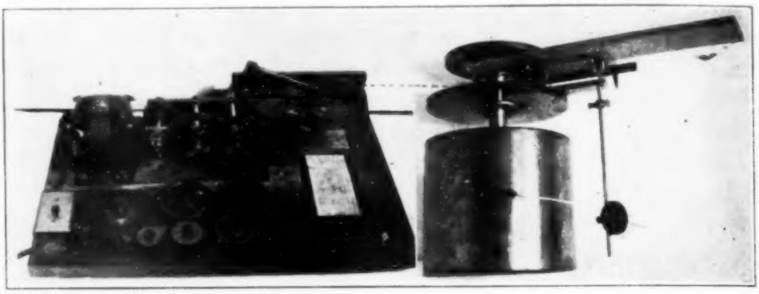
A mathematical analysis by Prof. W. Bartky, of the department of astronomy of the University of Chicago, resulted in curves of similar shape. He found that if the coefficient of viscosity is greater, there is no turning point for the tension, and it steadily increases.

The following experiments then were based on the conception that a tension curve of the force necessary to move rapidly a rigid body about a fixed axis would show a "dip" as the result of the development of velocity, whereas if it were opposed by a so-called viscous substance such a dip would be absent or markedly reduced.

The apparatus, devised after one constructed by Dr. L. C. Hutchinson, of the University of Minnesota, consisted of two parts: (1) a motor so geared that it would produce a to and fro movement of a shaft at any rate from 4 to 60 revolutions per minute; to this shaft was attached a belt which provided the force to move the second part of the apparatus; (2) a stationary drum through which passed a stationary steel axis rod that was fitted over a peg protruding upward from the table top. About this rod two fiber disks rotated freely on a ball-bearing spindle, independent of each other. To the lower disk was attached a holder in which flat springs of various strengths could be fixed, the length of these springs being varied by a sliding mechanism. When the lower disk was rotated by means of the belt, the spring impinged on a rod attached to the undersurface of the upper disk, to which was attached an arm board. The force necessary to move the upper disk at any moment, therefore, was determined by the deformation of the spring, and this was recorded by a writing lever moved by a string working about three pulleys. The lever made a record on the stationary drum, the move-

ment of the extremity being recorded in a horizontal direction, while the tension was developed in a vertical one. A time marker was attached to the rod to which the writing lever was attached and moved along with the arm-board bearing the fiber disk (fig. 2).

When one examines the curve obtained by this machine of a relatively rapid movement of the arm-board bearing a weight of about 5 pounds (2.3 Kg.), resisted by a spiral spring, the dip described as due to the turning point in tension is apparent (fig. 3*a*). When one



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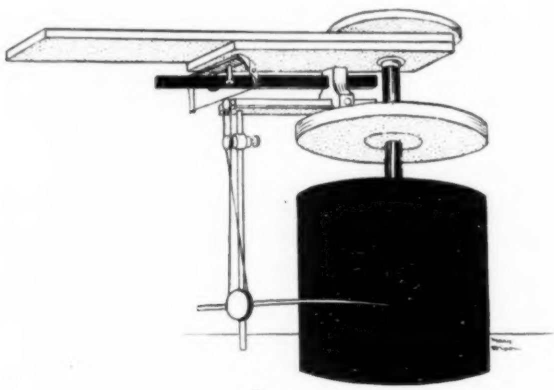

C

Fig. 2.—*A*, motor driven shaft. *B*, apparatus to record tension developed. *C*, drawing to show details of disks, arm-board, spring and recording mechanism.

now compares the curves obtained of the flexion or extension of the forearm of normal adults, the similarity of the curve is apparent (fig. 3*b*). As compared to the curve of normal muscles, which constantly show this type of curve, the tracings obtained from patients suffering from postencephalitic parkinsonism form a marked contrast. In many instances the curve obtained is almost identical with that when the movement of the weighted arm-board was resisted by a so-called viscous substance (fig. 4*a*).

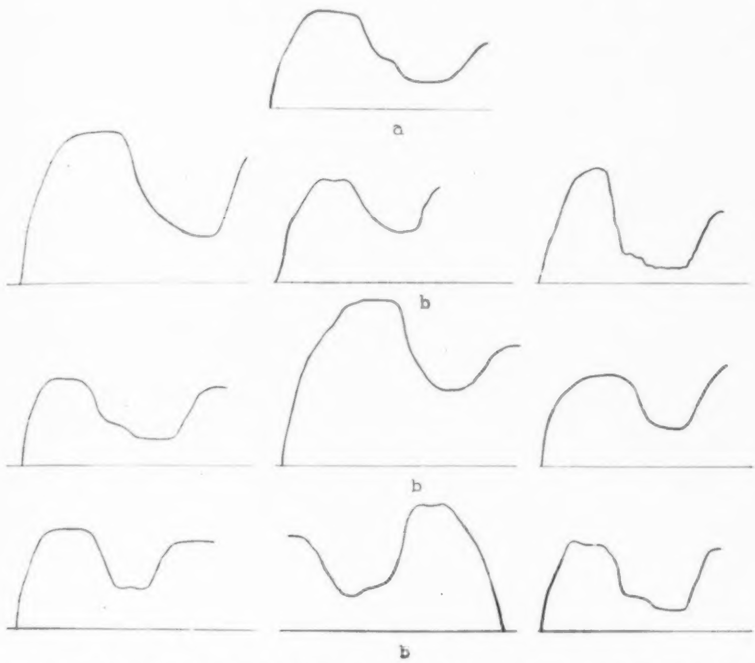

Fig. 3.—Velocity curves showing the dip that results from the extension of elastic matter: *a*, model; *b*, normal muscle. Note the similarity of curves.

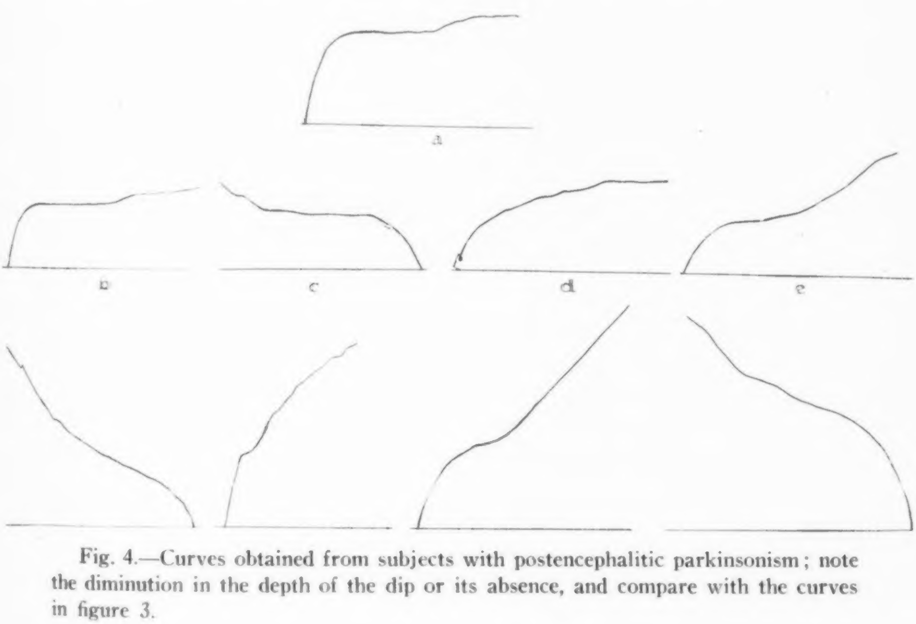

Fig. 4.—Curves obtained from subjects with postencephalitic parkinsonism; note the diminution in the depth of the dip or its absence, and compare with the curves in figure 3.

The characteristic feature of most of the curves was the diminution in the depth of the dip or its absence. The more marked the rigidity, the less frequently were any dips seen (fig. 4 *b, c, d, e,* etc.).

Prior to the taking of these tracings all treatment was discontinued for a number of days. When the patients were again placed on treatment with scopolamine, the tracing showed a change to one in which the dip reappeared (fig. 5). That this absence of a dip was not due to greater tension can be seen from a study of a case of myotonia atrophica when repeated flexions of the forearm were performed. At the beginning a very low tension was recorded, without any dip. As the flexions were repeated the tension increased, and a dip appeared.

The same conclusion may be reached from a study of the muscles of patients paralyzed as the result of disease of the pyramidal tract. In a series of patients with hemiplegia it was seen that although great

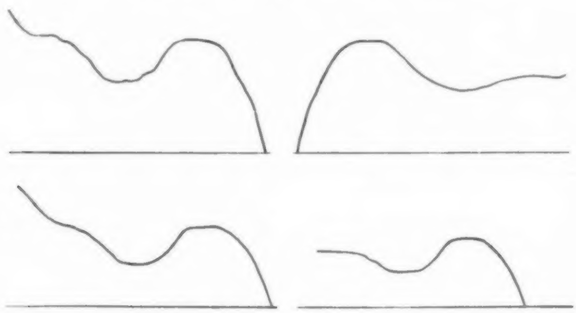

Fig. 5.—Curves obtained from the subjects in figure 4 treated with scopolamine; note the reappearance of the dip.

tension was present, the usual curve showed a marked dip. In both the patients with hemiplegia and those suffering from parkinsonism, after the dip tension rose to a higher point than was necessary to overcome inertia (fig. 6).

From this part of the study it was concluded that the muscles of patients suffering from parkinsonism possess great internal friction, which could be interpreted as a part of the so-called viscosity of solids.

This conclusion was strengthened by the observation that when the forearm was flexed and then the tension on the arm-board removed at the same rate of speed, the hysteresis loop was exceedingly large as compared to that seen in paralysis due to disease of the pyramidal tract (fig. 7).

SPRING DAMPING

When a flat spring, free at one end, is made rapidly to pull against a body rotating around a fixed axis, vibrations are produced in the spring. These vibrations persist if the movement of the body is opposed

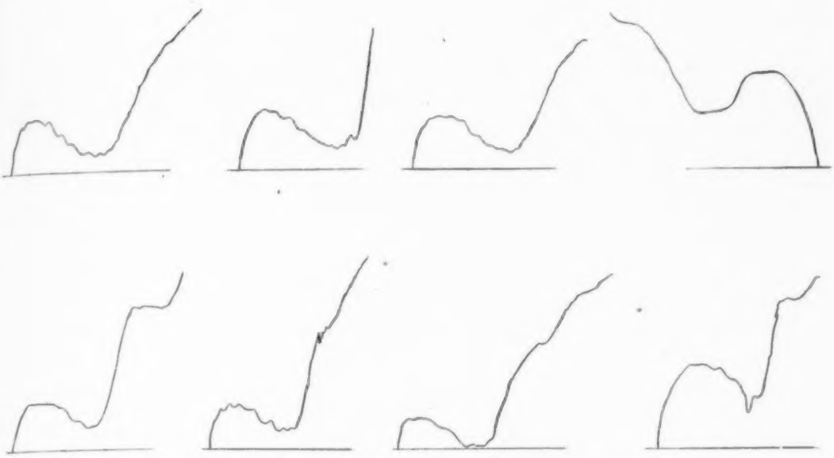

Fig. 6.—Curves obtained from patients with hemiplegia showing rise in tension after the dip.

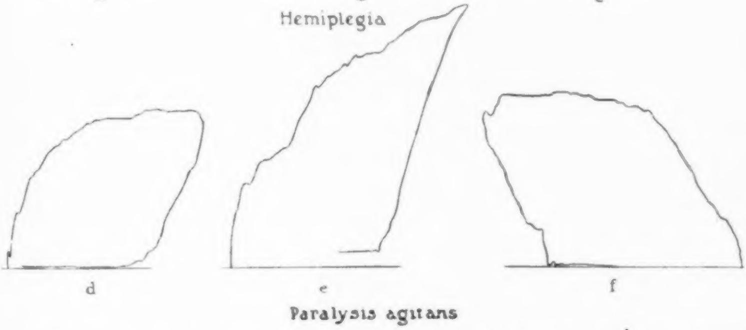

Fig. 7.—Difference in internal friction, or so-called viscosity of solids; between the muscles of patients with parkinsonism and those with hemiplegia as shown by the hysteresis loop.

by the force of a coiled spring or other elastic force (fig. 8*a*). If the movement of the body is resisted by a viscous body, the vibrations are markedly damped or disappear (fig. 8*b*).

To a motor driven shaft as already described, one end of a flat spring, 20 cm. long, 1 cm. wide and 20 mm. thick, was attached. To the other end of the spring was attached a small knob to which a belt was fastened. The belt rotated a small fiber disk on which a splint for an animal's extremity was fastened. The disk rotated about a ball-bearing spindle fitted into a shaft screwed into a table. A writing lever attached to the spring recorded tension and movement on a smoked paper laid flatly on the table.

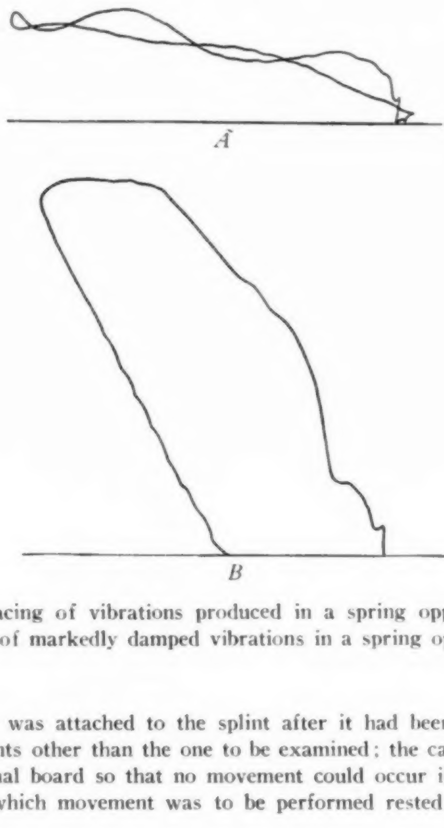

Fig. 8.—*A*, tracing of vibrations produced in a spring opposed by an elastic force; *B*, tracing of markedly damped vibrations in a spring opposed by a viscous body.

The extremity was attached to the splint after it had been immobilized by a plaster cast at joints other than the one to be examined; the cast also fastened the animal to an animal board so that no movement could occur in other extremities. The joint about which movement was to be performed rested on the axis of the disk (fig. 9).

A tracing of flexion or extension of an extremity of a normal cat with the muscles at rest showed marked waves of vibrations (fig. 10*a*). When the flexors were tetanized and extension was performed, the waves were damped (fig. 10*b*). This was likewise found in muscles in rigor mortis (fig. 10*c*). Deafferented and denervated muscles at rest showed marked waves (fig. 10 *d*, *e*).

In the decerebrated animals with the occiput up, flexion and extension of the extremity produced a record with marked waves (fig. 10*f*), but when the occiput was turned down and a tonic labyrinthine reflex elicited, the waves were damped (fig. 10*g*). When tonic labyrinthine reflexes were destroyed by removing the labyrinths, the tracings showed marked waves (fig. 10*h*). When muscle proprioceptive reflexes were destroyed by bilateral section of the first twenty-three posterior roots, and the spinal cord sectioned one segment above the lowermost root was resected, good decerebrate rigidity resulted in the forelegs from the tonic labyrinthine reflexes. Tracings of muscles so innervated showed damping of all waves (fig. 10*i*).

From this it would appear that muscles intoned by labyrinthine tonic reflexes show marked internal friction of so-called viscosity, whereas

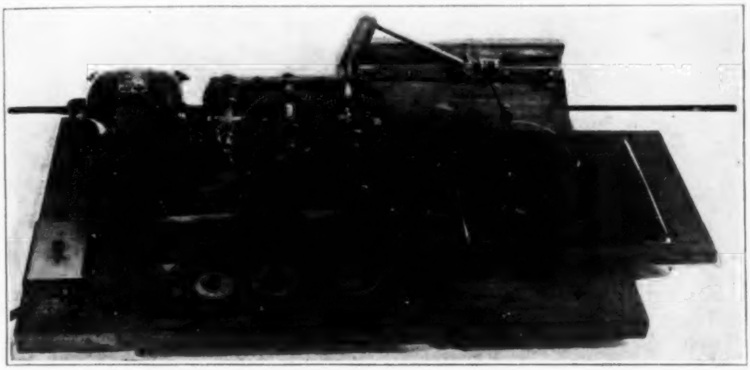

Fig. 9.—Motor driven shafts with attached spring, recording vibrations on smoked paper.

the muscles intoned by muscle proprioceptors show an elastic type of curve in the normal and decerebrate animal. Tetanized muscle and muscle in rigor mortis show a so-called viscous type of curve.

The hysteresis loops obtained from the several types of contracting muscles bear this out. Tetanized muscles and those intoned by tonic labyrinthine reflexes show very large loops in contrast to normal muscle (fig. 10 *j*, *k*).

In repeated extensions of an extremity in a decerebrated animal with the occiput down, the tensions progressively diminished as if fatigue had occurred. This is not the case, however, as the same low tension persists after rest (fig. 10*e*). In repeated extension of a tetanized muscle, actual fatigue occurs (fig. 10*m*). The former is only another expression of the plasticity or ductility of muscle when intoned by a labyrinthine tonic reflex.

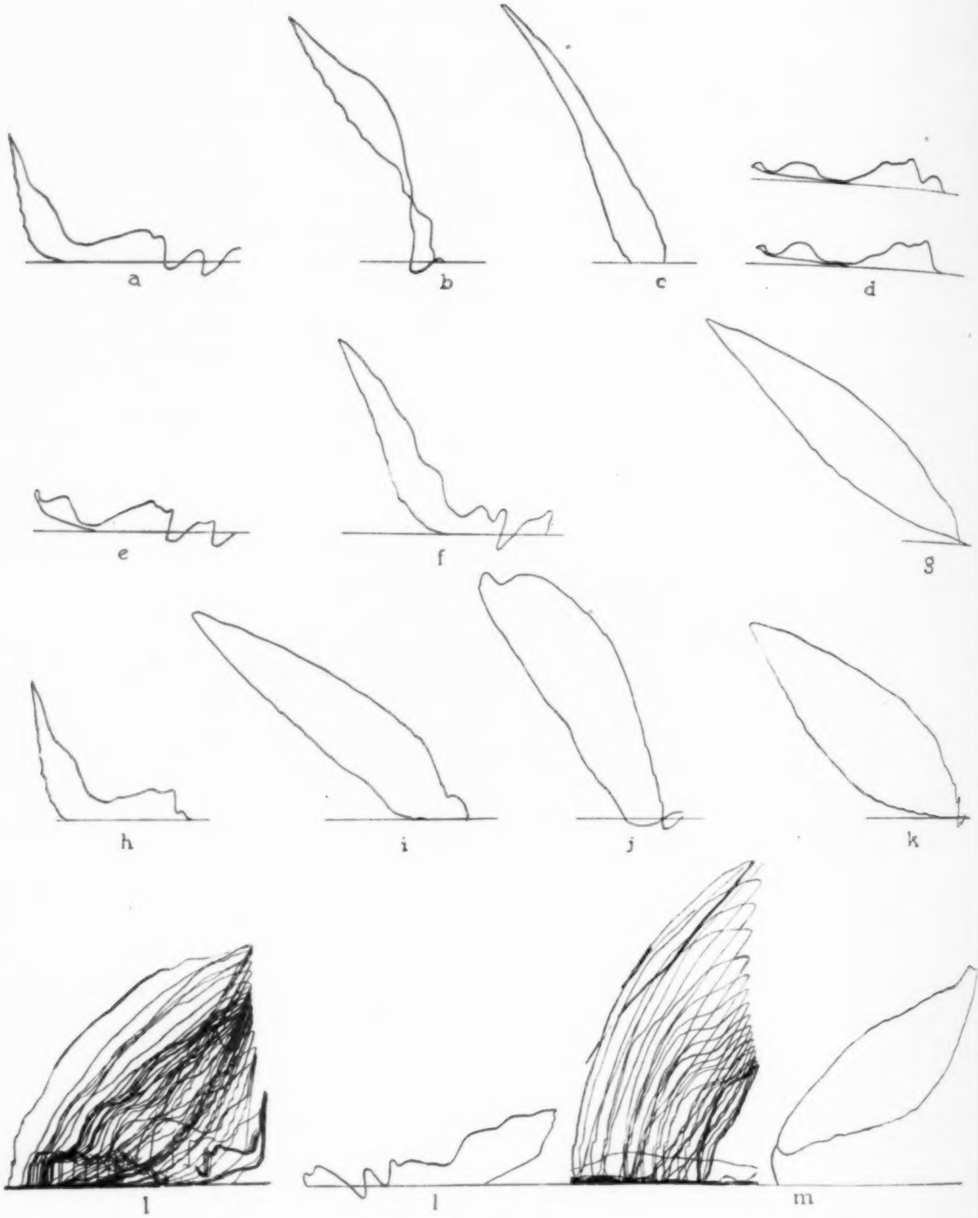

Fig. 10.—Tracings obtained from a normal cat during flexion and extension of an extremity. *a*, normal muscles at rest; *b*, flexors tetanized and then extended; *c*, muscles in rigor mortis; *d* and *e*, deafferented and denervated muscles at rest; *f*, muscles in decerebrated animals with occiput up in flexion and extension; *g*, elicitation of tonic labyrinthine reflex in muscles of decerebrated animal with occiput down; *h*, muscles with the labyrinthine reflex destroyed by removal of the labyrinths; *i*, labyrinthine reflex tone in completely deafferented extremity; *j*, hysteresis loop obtained in tetanized muscle; *k*, hysteresis loop obtained in tonic labyrinthine reflexes; *l*, low tension after repeated extension of extremity in decerebrated animal with occiput down; *m*, fatigue and recovery after repeated extension of tetanized muscle.

VISCOUS ELASTIC FLOW

Although one cannot assume that when a muscle is subjected to a strain it behaves as a solid, it is remarkable how similar some of the phenomena will be found.

In his characteristically lucid manner, the late Prof. Albert A. Michelson [15] described the laws of viscous-elastic flow. He said that:

When a solid is subjected to a strain beyond the "elastic limit" its behavior may be summarized as follows: First, the application of the stress results in a rapid elastic yield which if inertia be negligible, is practically instantaneous. If the stress be now removed, the specimen returns to its former position. Second, this is followed by a slower yielding whose rate, if the stress is not too great, diminishes with time, and which ultimately attains a constant value which may be zero. If the stress be now removed, the specimen returns almost instantaneously to a point short of its original position, and then continues at a much slower rate and ultimately comes to rest at a point short of its original position. The behavior of any solid under stress may be considered as the resultant of four elements:

A. The elastic displacement, which is characterized by being approximately proportionate to the stress and independent of time. *B*. The viscous-elastic displacement which is manifested in a slow return when the stress is removed and it is assumed that the same forces are brought into play during the direct motion. *C*. The viscous displacement when the elastic force is absent or very small in comparison with the viscous resistance. The specimen does not return to zero even after a long time interval. *D*. The lost motion. If the stress be applied for a short time, even a small fraction of a second, the specimen does not return to the original zero. The difference between the original and the new zero is the lost motion. The viscous-elastic and viscous yield are represented by the slow yield.

The type of strain selected for Michelson's investigations was the torsion of cylindric rods, as this is the only strain in which the form remains unaltered. He said that it was probable that the laws governing this special type may be made to include other distortions such as extension.

Accordingly, an apparatus was built whereby arm and leg boards for man and animals were attached to fiber disks rotating about a ball-bearing spindle. The disks were rotated by a weight placed in a scale pan to which was attached a belt passing over a pulley to the disk. The scale pan was lowered at a constant rate by a shelf which was lowered and raised by means of a motor-driven shaft moving at a speed that could be regulated, usually a complete rotation in sixteen seconds (fig. 11).

When the normal muscle of a cat or man is subjected, in general, to longitudinal stress within physiologic limits, the curve of the movement, as represented by the elastic limit, is one of an elastic substance (fig. 12*a*). When the normal muscle of a cat is tetanized by an induced

15. Michelson, Albert A.: The Laws of Elastico-Viscous Flow, Proc. Nat. Acad. Sc. **5**:319, 1907.

current we have observed that after a short period of immediate elastic flow there ensues a period of a viscous-elastic flow (fig. 12*b*).

Such a physical state in muscle resembles the ductile or viscous-elastic state of ductile solids, or it may be said to represent a low elastic limit, or early proportionality point. That is, if a certain group of muscles stretched their physiologic length show a stress-strain line that is straight, they have a relatively high elastic limit or proportionality point. The sooner this point is reached in the course of stretch,

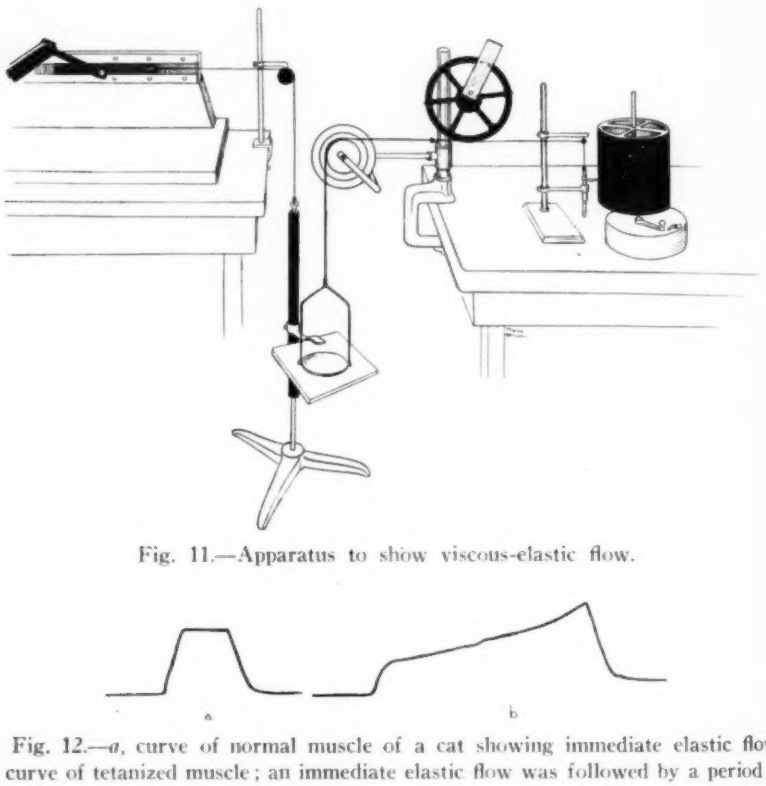

Fig. 11.—Apparatus to show viscous-elastic flow.

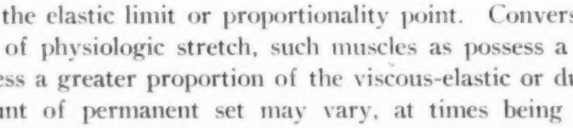

Fig. 12.—*a*, curve of normal muscle of a cat showing immediate elastic flow; *b*, curve of tetanized muscle; an immediate elastic flow was followed by a period of slow viscous-elastic flow.

the lower the elastic limit or proportionality point. Conversely, within the limits of physiologic stretch, such muscles as possess a low elastic limit possess a greater proportion of the viscous-elastic or ductile stage. The amount of permanent set may vary, at times being great with greater, at times with lesser, ductility. The internal resistance may likewise be variable.

The muscles of a deafferented extremity show a purely elastic flow within physiologic limits (fig. 13*a*). The well known viscous-elastic

flow of a muscle in rigor mortis is shown to point out the fact that in this condition the time necessary to produce a flow is enormously increased as compared to that necessary for a living muscle (fig. 13*b*). When an animal had been decerebrated by the anemic method, and good rigidity was present with the occiput up, the tracing showed an elastic curve (fig. 13*c*). When the occiput was turned down, the elastic limit was reached before the end of the physiologic movement, and a slow flow followed (fig. 13*c*).

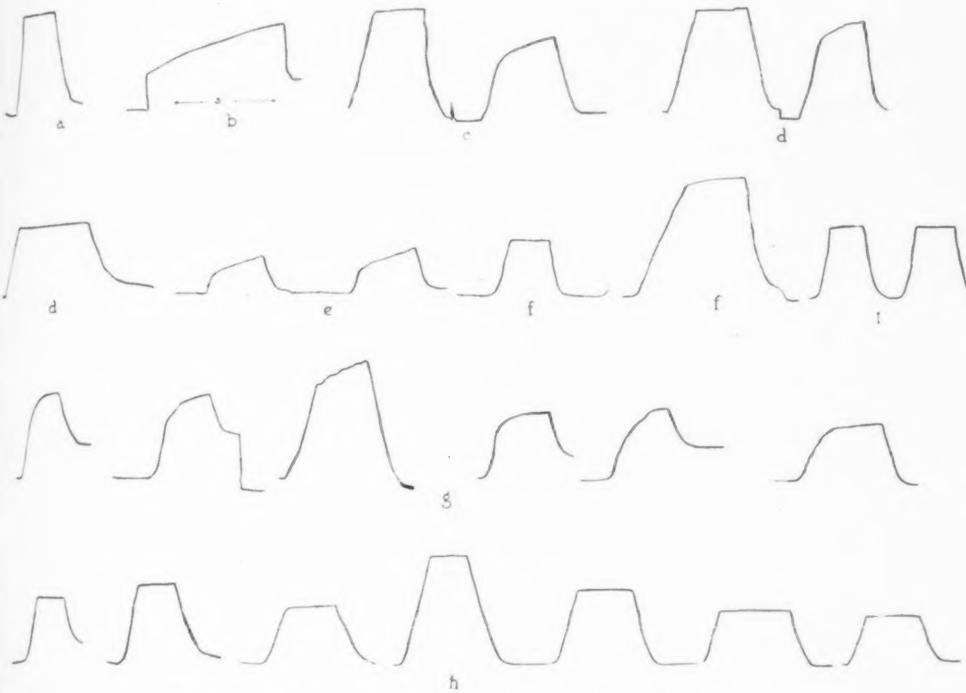

Fig. 13.—Tracings of viscous-elastic flow referred to in text.

In a decerebrated labyrinthless animal with good rigidity, no true viscous-elastic flow could be demonstrated (fig. 13*d*).

Finally, in a decerebrate animal with both upper extremities deafferented by section of the first twelve dorsal roots of both sides, and with excellent rigidity, the curve obtained was that of a viscous-elastic substance (fig. 13*e*).

From this study it may be concluded that muscles in a state of electrically induced tetanus and muscles intoned by the labyrinthine tonic reflexes show a viscous-elastic flow, whereas normal, deafferented and denervated muscles show an elastic flow.

Similar tracings on man showed that normal muscles as a whole possess a high elastic limit, or that the entire flow is elastic (fig. 13*f*). In marked contrast to this (fig. 13*g*), the curves of patients suffering from parkinsonism invariably showed a relatively low elastic limit and a marked viscous-elastic flow. The permanent set was always pronounced. In contrast to this, the tracings of patients suffering from hemiplegia all showed a clearly elastic curve (fig. 13*h*).

CONCLUSIONS

1. Normal muscle and other muscle preparations possess a high elastic limit and little internal friction.

2. Muscle in rigor mortis and tetanized muscle possess high internal friction of so-called viscosity and a marked viscous-elastic flow.

3. Several methods of examination show that muscles intoned by labyrinthine tonic reflexes possess both high internal friction of so-called viscosity and a large viscous-elastic flow.

4. Muscles of patients suffering from parkinsonism possess both high internal resistance of so-called viscosity and a large viscous-elastic flow.

5. The muscles of patients suffering from hemiplegia possess a high elastic limit and less internal friction of so-called viscosity.

QUANTITATIVE STUDIES ON THE HUMAN MUSCLE TONUS

II. AN ANALYSIS OF EIGHTY-TWO NORMAL AND PATHOLOGIC CASES

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In a previous contribution, McKinley and I[1] described a new method for obtaining quantitative measurements of human muscle tonus. The principle of our technic is analogous to the usual clinical method of estimating tonus; that is, the resistance of resting, or at least voluntarily relaxed, muscles to passive stretch is determined.

TECHNIC

An arm of the subject to be tested is placed on a freely rotating arm rest which is driven in a horizontal position on a ball-bearing axis by the release of a weight. The internal condyle is carefully placed directly above the axis, and the forearm is passively extended or flexed by releasing a weight with a trip mechanism. The angular distance and the velocity of the moving forearm are recorded on a smoked drum with an electric time marker.

To measure tonus under different conditions my associates and I have developed three methods, more or less similar in principle, for the quantitative recording of the pull of resting muscles around the elbow joint in flexion or extension. In the first method it is possible, within a fraction of a second, to measure the physiologic resistances around the joint during passive flexion or extension. The tonus torque is determined by noting where the positive acceleration of the machine resulting from a known driving force (T) becomes decelerated by the torque of the resisting muscles (T_m). This method was fully described in our first paper.

In the second and third methods, the time factor is not considered, but the physiologic resistance of the muscles to passive stretch is determined by reading the angular extension or flexion of the arm in terms of degrees for varying torques applied. Since the latter two methods have not been previously described, they will be discussed now.

Technic of Obtaining the Tracings in Method 2.—In method 2 the apparatus is the same as already described except that the time marker is employed merely to record the angular position of the arm on the drum. The subject's arm is passively swung outward (extended) and inward (flexed) three or four times and then released, and the "resting position" or "neutral point" of the arm as defined in method 1 is thus determined. By pressing an electric key the time marker

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1. McKinley, J. C., and Berkwitz, N. J.: Quantitative Studies on Human Muscle Tonus, Arch. Neurol. & Psychiat. **19:** 1036 (June) 1928.

records on the drum the position of this neutral point. Then a 100 Gm. weight is hung on the brass rod which extends the arm, and the forearm is again swung in the same manner. As soon as the arm comes to rest, the new position of the arm, which I shall call the "point of balance," is recorded by pressing the electric key. Other points of balance are similarly obtained for a series of weights: 200, 300, 400, 500, 750 and 1,000 Gm. By repeating the procedure, but hanging the different weights on the other brass rod, readings are obtained for the arm in flexed positions.

Technic of Obtaining the Tracings in Method 3.—In this method the "resting position" that the arm assumes without weights is determined as in the foregoing two methods, and the brass rods are then clamped by means of the trip mechanism which has been described in our previous paper. Then a 100 Gm. weight is hung on the rod which extends the arm, and the clamp to that rod is released. When the other rod is released by the experimenter, the falling 100 Gm. weight extends the arm to a new position (point of balance) which is recorded by pressing the electric key. The unweighted rod is then clamped, to hold the extended arm in its new position, while the weight of 100 Gm. is increased to 200 Gm. on the first rod. The clamp is again released, and the new point of balance is recorded. This procedure is continued for the same series of weights as used in method 2, and is then repeated with the weights hung on the brass rod which flexes the arm in order to measure the resistance of muscles to flexion. The comparisons of the values and results of the three methods will be discussed later.

STUDY OF NORMAL SUBJECTS

Studies were made of fifty-two normal persons, including the two normal subjects who were discussed in our previous paper. In order to obtain a fairly uniform group, the subjects chosen were medical students and laboratory technicians. The routine was standardized as much as possible, and the laboratory was selected with freedom from external influences in view. Although ideal conditions were not attained, as the room was not specially constructed and located so as to eliminate all casual noises, changes of light, street cries, slamming of doors and the like, in general, external interference appeared to make only inappreciable differences in the observations.

After the subject was seated in the manner described in our first paper, the forearm was swung slowly back and forth by the experimenter and then released. If the subject was relaxed and exerted no voluntary or involuntary control over the forearm, it invariably stopped at a 90 degree angle (plus or minus 3 degrees) with the upper arm. If the arm of normal persons either stopped at some other angle or kept on swinging for several moments, it was interpreted as indicating that the muscles of the arm were not relaxed. In the former case, if the examiner moved the arm rest, he noted that the subject's arm offered considerably more resistance than if it were relaxed, and if the position of the arm was changed it frequently remained in that new position instead of returning to the original "neutral point." In the latter case, where the arm continued to swing, it was obvious that the subject was exerting voluntary control and that the arm was not completely relaxed.

Whenever the conditions described showed that the subject had failed to relax, the words: "Please relax as completely as you can" were repeated, and the forearm again was swung back and forth by the experimenter. Some of the subjects who showed poor relaxation contended that they were relaxed. Insisting that the subject was not well relaxed did not always help matters, and in some instances the

subjects became more tense in their anxiety to cooperate. Therefore, the experimenter only encouraged the subject by repeating the words: "Now, let your arm be limp and relaxed," and the experiment was continued. It usually took twenty minutes to test each arm. As a rule, the left arm was tested first with the three methods, and after a few minutes of rest, the right arm was tested. The same procedure was followed throughout so as to standardize the technic. For a check, the right arm was tested first in a few cases, but this alteration in the order of the experiment did not affect the results. Several of the subjects were tested in more than one sitting. One person (case 1) was tested twenty-three times over a period of two years (table 1). It was found that subjects who gave regular tracings the first time, gave regular tracings in repeated tests, and that subjects who gave irregular tracings at first, continued to give irregular tracings in subsequent examinations. However, even the subjects who gave fairly constant readings showed voluntary or involuntary interference in their tracings at times. After testing each arm in the routine manner, the tracings were roughly examined, and if any gross irregularities were seen or if the subject showed difficulty in relaxing, a few additional readings were usually taken.

TABLE 1.—*Forty-Nine Tracings Taken in Twenty-Three Sittings Over a Period of Two Years by Method 1 with a 500 Gm. Driving Machine (Case 1—Normal Woman)*

	Right Elbow				Left Elbow			
	Degree of Extension		Degree of Flexion		Degree of Extension		Degree of Flexion	
	T-To	Length of Tracing	T-To	Length of Tracing	T-To	Length of Tracing	T-To	Length of Tracing
Average	42.8	88.7	24.0	44.6	49.6	99.0	23.1	42.9
Standard deviation	±5.5	±9.3	±2.5	±3.0	±4.8	±6.5	±2.8	±3.6

TRACINGS OF A TYPICAL NORMAL SUBJECT

One of the female subjects studied (case 1)—a laboratory technician described in our previous paper who gave fairly regular tracings from time to time over a period of two years—may first be discussed. In table 1 are placed the averages from collected readings of this subject derived from method 1, using a 500 Gm. weight to drive the machine. The table includes the tonus torques, or the values in degrees of $T = T_0$, and lengths of these respective tracings. The derivation and significance of the expression $T = T_0$ were described in the previous paper. At the foot of table 1 the arithmetic mean of the items above is presented. To ascertain the dispersion of these items about their arithmetic average the standard deviation was calculated, using the formula commonly employed in statistical studies:

$$\sigma = \sqrt{\frac{\Sigma d^2}{n}}$$

in which σ is the standard deviation, $\Sigma\, d^2$ is the sum of the squares of the deviation from the average, and n is the number of items in the series.

The variations in readings from day to day are not more marked than the variations that occur in one sitting. The variations that do exist, beyond the 3 per cent error in reading the tracings which is not large, are probably explainable by one of two factors. Either the arm is not placed properly on the arm rest and the medial epicondyle is not directly over the axis of the machine, or the subject is not sufficiently relaxed and interferes while the tracings are being taken. The machine itself has been shown in our first paper to be no factor in this matter. To decide the probable cause of these variations appearing in table 1, the experiment was checked with the following procedure.

Tracings were taken of the same subject (case 1) in fifteen different sittings, in one afternoon. A series of three or more tracings was taken in each of the fifteen sittings. Since the average length of this patient's tracings, as seen in table 1, exceeded 80 degrees and the experimenter wished to avoid the consequent deformation at the end

TABLE 2.—*Thirty-Two Tracings of Left Arm in Fifteen Sittings Taken in One Afternoon by Method 1 with a 300 Gm. Driving Machine (Case 1—Normal Woman)*

	Degree of Extension		Degree of Flexion	
	T-To	Length of Tracing	T-To	Length of Tracing
Average	19.4	38.9	14.2	25.5
Standard deviation	±2.1	±3.1	±1.7	±2.3

of the tracing, a 300 Gm. weight instead of the usual 500 Gm. weight was used to drive the machine, and the length of the tracings was thus shortened. After each sitting the subject was allowed to leave the chair for a few minutes, and both the elevation of the seat and the position of the chair were altered so that the subject would not be seated in identical positions each time. The usual precautions were taken in arranging the subject for each test. The averages of these sittings are shown in table 2. The figures from both table 1 and table 2 show that the average tonus torque obtained from a group of tracings in a single sitting compared with the average torque obtained from the group of tracings in any other sitting shows about the same variation as in individual tracings from the same sitting compared with one another. This indicates that variations are apparently due to subjective interference, and not to improper position of the arm.

Percentage frequency graphs of case 1, shown in table 1, are illustrated in figure 1. The tonus values ($T - T_0$) and the respective lengths of these tracings are represented in black and white bars. The ordinates represent the percentage frequency of the tests, and the

abscissae represent the angular extension in degrees which the forearm travels from the "neutral point" after a 500 Gm. weight is released. As is shown in table 1, forty-nine individual tracings were taken in twenty-three different sittings. Figure 1 (method 1) shows the percentage frequency graph of the individual tracings, represented by black bars, and the percentage frequency of the average tracings in each sitting, represented by white bars. Very little difference exists between the percentage frequency graph of the individual tracings and the percentage frequency graph of the average tracing in each sitting.

By further examination of table 1 and figure 1, it is seen that the entire lengths of the tracings in degrees are about twice the values of

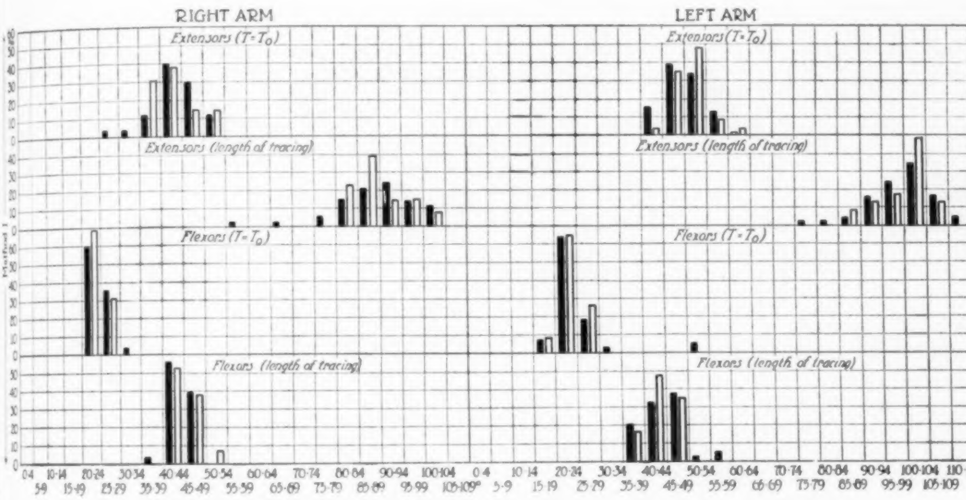


Fig. 1 (case 1).—Normal woman. The ordinates represent the percentage frequency of the tracings, and the abscissae represent the extension and flexion of the arm in degrees with a 500 Gm. weight activating the machine. The black bars represent the percentage frequency of thirty-three tracings of the right arm and forty-nine tracings of the left. The white bars represent the percentage frequency of the average tracing obtained at each of the thirteen sittings with the right arm and twenty-three sittings with the left. Both the tonus torques ($T = T_o$) and the length of the tracing are illustrated.

the corresponding tonus torques, or the length of angular acceleration is equal to the length of angular deceleration, and passively stretched muscles behave in this respect like elastic bodies. This elasticity of muscles is more obvious in table 2 than in table 1, because the length of the tracings in the former table does not extend beyond 80 degrees from the neutral point in the former, and hence the deformation due to shifting of the axis does not appear. Practically all soft tissues

of the body have more or less elasticity, as has been shown by Vierordt,[2] but muscle follows Hook's law very well within the limits of ordinary physiologic extension of the muscle. The same conclusions were reached by McKinley and Wachholder[3] in their studies on rabbits. By rigidly fixing the extremity to be studied, they eliminated the possibility of shifting the axis, and they found that completely relaxed muscle stretched by passive movement acts practically like a perfect elastic body.

The tonus torque of both the right and the left arm in table 1 and in figure 1 may now be compared. The degree of extension of the left elbow is shown to be greater than that of the right. In other words, the tonus is less in the left arm than in the right. It is true that the right forearm is about 100 Gm. heavier than the left, but in our previous paper we have shown that the variations in the moments of inertia and the weight of the extremity under study do not

TABLE 3.—*Average of Six Tracings Taken in Different Sittings on Different Days by Method 2—Pendulum Method. (Case 1—Normal Woman)*

Weights Driving Machine, Gm.	Right Elbow		Left Elbow	
	Degree of Extension	Degree of Flexion	Degree of Extension	Degree of Flexion
100	9	5	11	8
200	21	15	24	18
300	35	23	42	24
400	56	30	66	30
500	75	36	82	35

influence the evaluation of the tonus torque. In our previous paper we increased the moments of inertia of the arm and machine by attaching weights to the arm rest and found that by even doubling the moments of inertia of the machine, no appreciable change in the tonus torque values was observed.

By comparing the resistance of movement in flexion with that of movement in extension (table 1) it appears that there is nearly twice as much resistance of muscle to stretch in the former. This would suggest that there exists more tonus in the flexor muscles than in the extensors. However, we have shown in our previous paper that one can compare only tonus torques of homologous muscles acting on homologous joints.

The results of method 2 and method 3 with the same subject (case 1) will be discussed together, since the technic and the results

2. Vierordt, H.: Anatomische, physiologische und physikalische Daten und Tabellen zum Gebrauche für Mediziner, Jena, Gustav Fischer, 1906.

3. McKinley, J. C., and Wachholder, K.: Ueber das sogenannte Bremsungsphänomen in Muskeldehnungskurven, Ztschr. f. d. ges. Neurol. u. Psychiat. **121**:24, 1929.

of these two methods have much in common. The average angular distances through which the arm is moved by the different weights are listed in tables 3 and 4. An examination of these two tables disclosed the same slight variations with occasional gross variations as appeared in table 1 derived by method 1. Again, the same factors produce variations in the tracings, namely, the improper position of the arm and the subjective element in which personal interference with the tracing occurs. The latter factor occurs more frequently in method 3 than in the other two methods, because the procedure takes a longer time, allowing the subject more opportunities for interference. In method 2, as already stated, the arm is swung to and fro a few times and then released, permitting it to come to its new point of balance. The swinging usually helps the subject relax the arm. This is, as a matter of fact, the clinical means by which a patient is shown how to relax. But in method 3 the muscles have a chance to accommodate them-

TABLE 4.—*Average of Seven Tracings Taken in Different Sittings on Different Days by Method 3—Static Method. (Case 1—Normal Woman)*

Weights Driving Machine, Gm.	Right Elbow		Left Elbow	
	Degree of Extension	Degree of Flexion	Degree of Extension	Degree of Flexion
100	2	1	2	2
200	11	7	14	11
300	25	16	29	20
400	42	22	52	24
500	61	29	73	30

selves to their new lengthened or shortened states, and while the arm slowly comes to its new point of balance, the subject, if not very well relaxed, is apt to interfere, probably subconsciously, and thereby give irregular records.

The average extension of the right arm under the influence of any particular weight differs from the average obtained for the left arm with the same weight as in method 1. The person just discussed (case 1) is right-handed, and her right arm is shown (table 1) to offer more resistance to passive movement in all of the three methods. The reverse was found in left-handed subjects. Of fifty-two normal subjects studied, four were left-handed. Two of these subjects (cases 36 and 38) gave irregular tracings and hence unreliable data, although their records suggested more tonus in the left arm. The other two subjects (cases 37 and 51) gave fairly constant tracings, and their readings, obtained by all three methods, show that more tonus existed in their left arms than in their right (fig. 2).

Figure 3 illustrates the average of all tracings obtained by the three methods of measurement. The curves appear almost as straight lines in the three methods. The curves representing the same weights with

methods 1 and 3 show a lag at the beginning and then run fairly parallel to the curve derived by method 2. This lag was first described by Rieger,[4] who called it the "brake phenomenon (*Bremsung* phenomenon)," and its significance has been discussed by various investigators. Kuntz and Kerper [5] have studied this condition, using Spiegel's machine, in taking tonus tracings of cats and dogs. They have stated that muscle offers a greater resistance at the beginning of passive displacement when the knee is only slightly flexed than when the knee is flexed over a large angle. They took readings before and after the sympathetic system was removed and reported that the "brake phenomenon" practically disappeared following sympathectomy. From their experiments they concluded "that plastic tonus is mediated through the sympathetic nervous system."

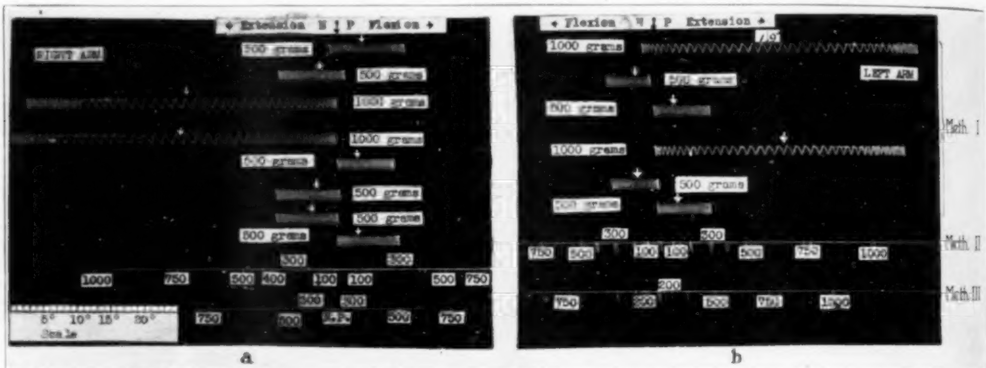


Fig. 2 (case 37).—Normal man. Tracings of a left-handed subject, who gave regular tracings. Note that the lengths of the tracings are greater in the right arm, indicating less tonus in that extremity. The arrows above the tracings indicate where the tonus torque ($T = T_0$) is measured.

McKinley and Wachholder [3] made a careful study of this condition in the rabbit. By painstakingly avoiding any shifting of the axis of rotation and increasing the driving load slowly, they found that the "brake phenomenon" was almost completely eliminated. They thought that this condition is largely a mechanical affair due to various extraneous factors. I do not think that I can adequately explain the "brake phenomenon" with the data I have at present. However, the curves in figure 3 show that by stretching muscles gradually, as in

4. Rieger, Konrad: Untersuchungen über Muskelzustände, Jena, Gustav Fischer, 1906.

5. Kuntz, A., and Kerper, A. H.: An Experimental Study of Tonus in Skeletal Muscles as Related to the Sympathetic Nervous System, Am. J. Physiol. **76:**121, 1926.

method 2, by a gradual application of a load, the "brake phenomenon" tends to disappear.

Figure 3 again shows that more tonus exists in the right arm than in the left in all three methods.

TRACINGS OF NORMAL SUBJECTS DISCUSSED COLLECTIVELY

I have already stated that many persons fail to relax satisfactorily and thereby interfere while tracings are being taken. Others relax so well that the slight variations in their tracings are within the limits of biologic error. In figure 4 is shown a person who gave irregular tracings, and it can be noted that sometimes he held his arm for a fraction of a second and then shoved it. Sometimes he shoved at the onset when

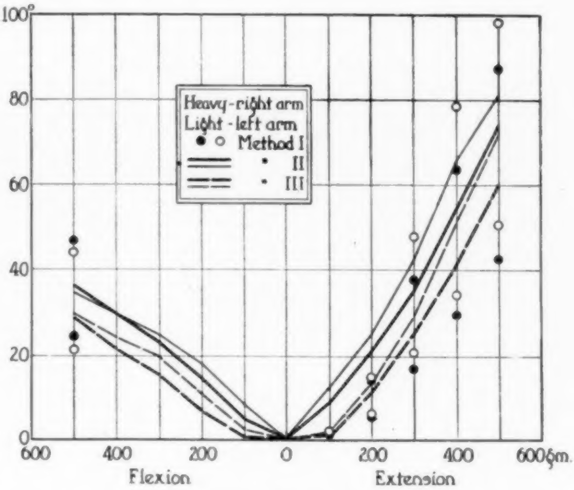


Fig. 3 (case 1).—Normal woman. Graph comparing the average of all tracings obtained by the three methods of measurement. The ordinates represent the degree of extension and flexion; the abscissae represent the weight in grams used to drive the machine. The lower pairs of circles represent the tonus torque ($T = T_0$), and the upper pairs represent the "total length of tracings."

the arm was released, while at other times he interfered toward the end of the tracing. These interferences (either voluntary or involuntary) are present in tracings obtained by all three methods. Method 1 records the entire movement of the arm, and it is so rapid that any interference results in a pronounced alteration of the tracing. In the other two methods the time occupied by taking the records is lengthened and the subject has more time to interfere if he is not well relaxed. Since the data are unreliable for a quantitative measure of muscle tonus if there is any interference by the subject, the subjects were arbitrarily divided into three groups. In group 1 were placed those subjects who gave

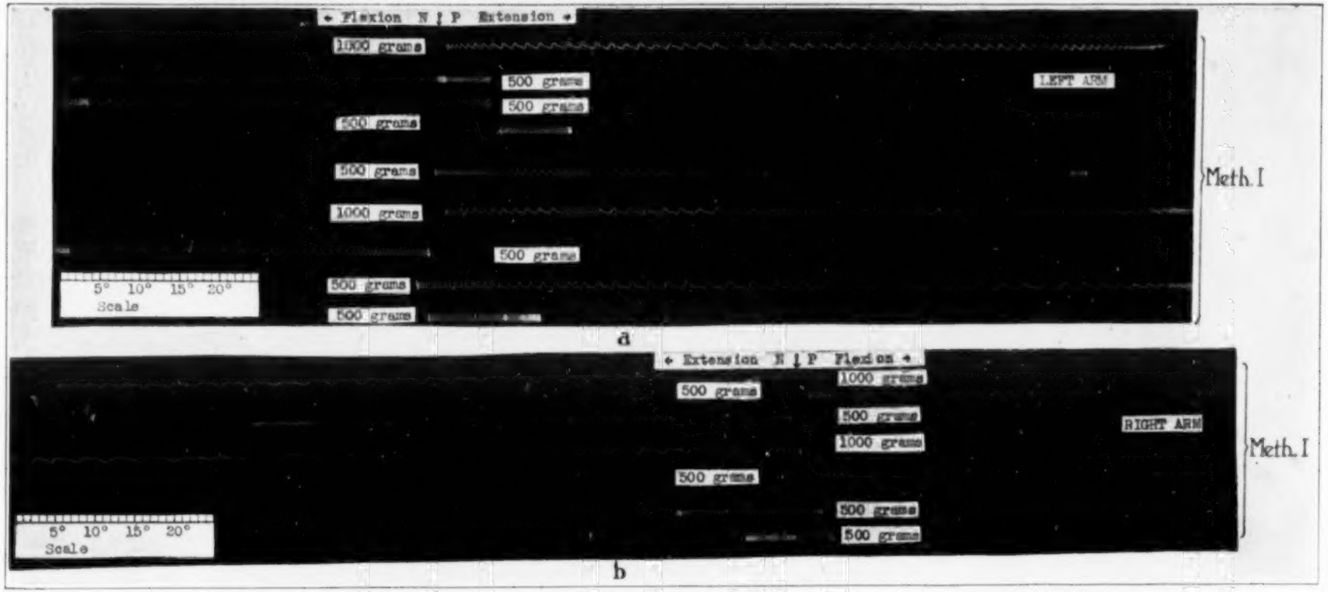
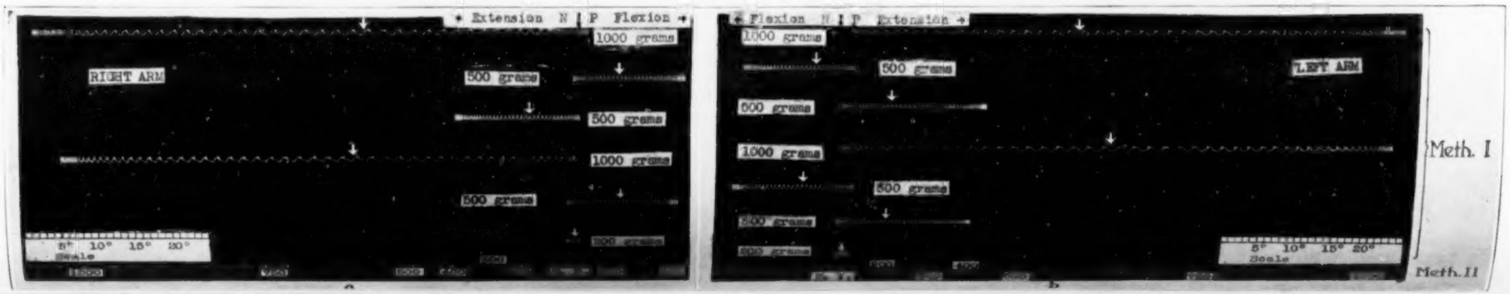


Fig. 4 (case 7).—Normal man; irregular group. The inequality in the lengths of the tracings indicates subjective interferences. Note that the second tracing of the left arm illustrates the arm actually stopping and proceeding during the course of the tracing. Some of the tracings obtained with the 500 Gm. weight are longer than those obtained with the 1,000 Gm. weight, indicating that the arm was not fully relaxed. The tonus torques were not determined because true tonus determinations are impossible in irregular and inconstant tracings.



regular tracings fairly constantly (figs. 5 and 6) and thus probably interfered to a minimal degree. In group 2 were gathered the subjects who gave doubtful results. These subjects were actually on the borderline, for although they repeatedly gave several regular tracings, from

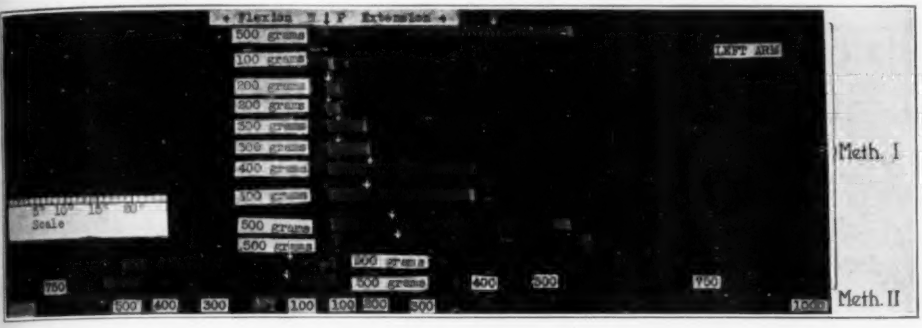


Fig. 6 (case 44).—Normal man; regular group. The lengths of the tracings and the tonus torques (indicated by arrows) are fairly comparable when similar weights are used to drive the machine.

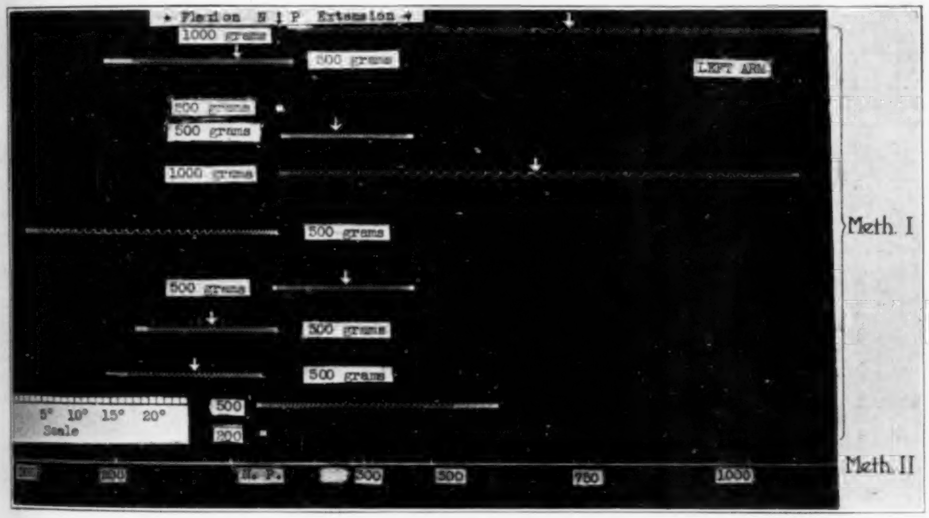


Fig. 7 (case 22).—Normal man; questionable group. The majority of the tracings are comparable when similar weights are used to drive the machine, although at least one third of the tracings showed definite interference.

one to two thirds of the tracings taken showed definite interference (fig. 7). In group 3 were placed those subjects who showed marked variability in practically all of their tracings (fig. 4). Of the thirty-four normal male subjects studied, seventeen came under group 1 (regular

group), six were in group 2 (questionable group), and eleven were in group 3 (irregular group). Of the seventeen normal female subjects studied, six were in group 1, four were in group 2, and seven were in group 3.

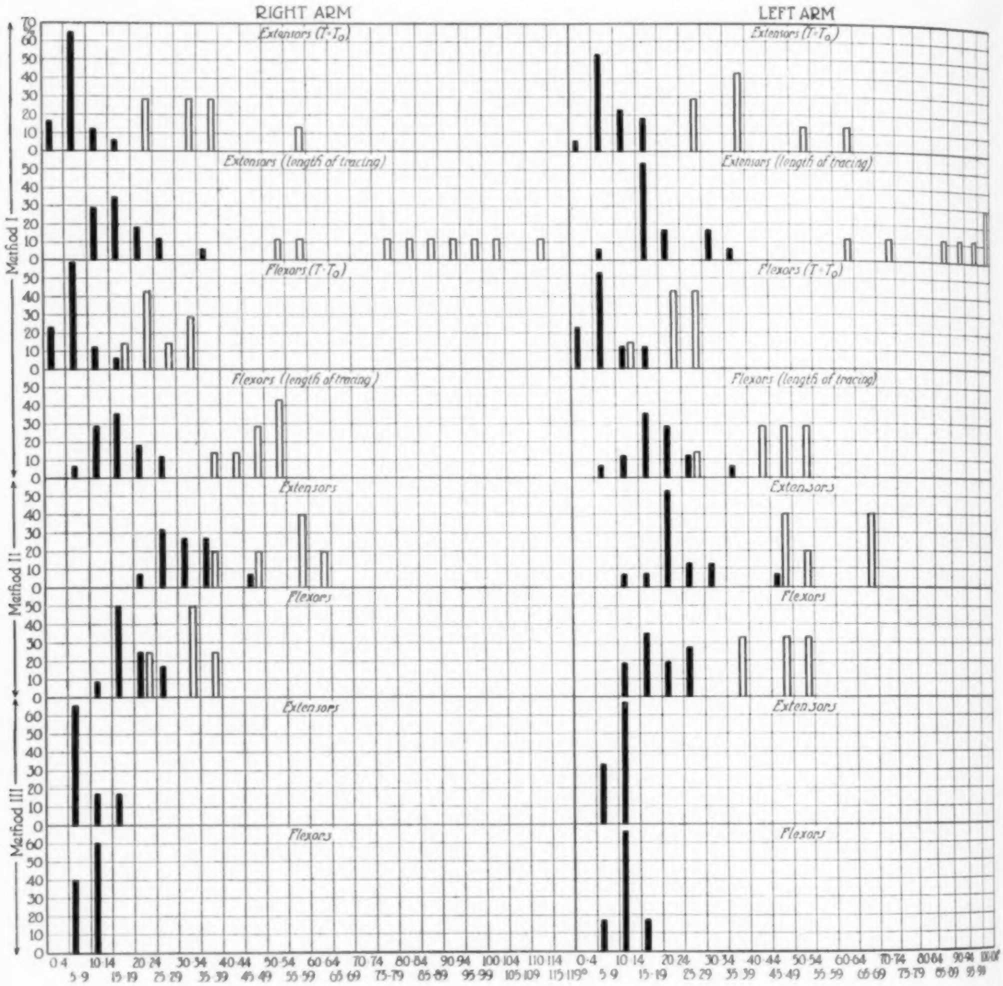


Fig. 8.—This figure shows the comparison of seventeen normal males and seven normal females. The ordinates represent the percentage frequency of the tracings, and the abscissae represent the extension and flexion of the arm in degrees with a 500 Gm. weight activating the machine. The black bars represent the male, and the white, the female. The three methods are indicated on the left of the graph.

Since irregular tracings are doubtless due to interferences of the subject, the data derived from groups 2 and 3 did not give true tonus

evaluations, and therefore a statistical treatment of such results would be fruitless. Only twenty-three of the fifty-two subjects studied relaxed sufficiently to give constant readings, and their data are shown in percentage frequency graphs in figure 8.

Figure 8 represents the individual tracings obtained from the male and female subjects of group 1. The graphs are not very smooth, apparently because the group of subjects illustrated is small. Comparisons are made of methods 1, 2 and 3. In all three methods a 500 Gm. weight was used to activate the machine. This figure shows that the left arm extends furthest from the neutral point in both flexion and extension in all three methods, indicating less tonus in this arm than in the right. Figure 8, method 1, also shows that the lengths of the tracings are almost twice the values of the tonus torques ($T = T_0$) in both flexion and extension, which again illustrates the high degree of elasticity which resting muscles possess, acceleration and deceleration being equal in length. This figure further shows that the arm is not moved with the 500 Gm. weight as far in method 2 as in method 1, possibly because of the lag ("brake phenomenon") which occurs at the onset of the tracing. The males are shown in black and the females in white. The right arms of both males and females are shown on the left side of the graph, and the left arms are shown on the right. The females are not represented in method 3 because of insufficient data. The female subjects appear to have less tonus than the male subjects in this graph, as the muscles are shown to offer less resistance to passive stretching.

ADDITIONAL OBSERVATIONS ON NORMAL SUBJECTS

In order to make additional observations on tonus, I introduced, during the course of the studies, other factors not previously mentioned. After the usual procedure had been completed, ten successive subjects were given a dynamometer to squeeze in the free hand while tracings were being taken by method 1. The compressing strength of the free hand was first determined, and for the experiment itself the subject was asked to exert one-half that strength while the tonus of his other arm was being recorded in extension. It was found that the tonus increased invariably in the contralateral arm.

In ten more cases, after studies by the three usual methods, the arm was extended by a 1,000 Gm. weight and held in extension for a period of sixty seconds. The weight was then removed and the new resting position of the arm noted. The arm was also flexed and released in the same manner. It was observed that the arm did not return all the way to the original neutral point, but remained 3 or 4 degrees from it. By this experiment the lengthening and shortening reactions of muscles can

be graphically obtained. Subjective interference vitiated the results in a small percentage of these cases.

In another group of ten subjects, after determining the resting point of the arm, the experimenter held the arm extended at 20 degrees from the resting point for a period of twenty seconds, then released it and observed the new resting point reached. This procedure was repeated, holding the arm at 40 degrees and also in flexed position at 20 and 40 degrees. It was found that the arm returned closer to the original neutral point from 40 degrees than it did from 20 degrees. This experiment suggests that if an arm is moved within a short range from the neutral point, there is practically no reflex mechanism acting, and the muscles remain in their new lengthened or shortened states.

STUDY OF PATHOLOGIC SUBJECTS

Thirty subjects with various types of muscle tonus disturbances were also studied. It was found that method 1 was the most satisfactory for recording the observations of these subjects, because it records changes taking place along the entire excursion of the arm. A greater proportion of this group failed to relax than of the normal group previously discussed. An explanation for this fact is that they were of less intellectual capacity than the normal subjects. The pathologic group was recruited from the wards of a charity hospital, while the normal subjects were practically all college students in whom one would naturally expect better cooperation.

Nine of the subjects had paralysis agitans. The tremors of the involved arms, as well as increased tonicity, were graphically recorded in the tracings. The tremors usually decreased or disappeared if the arm was rapidly extended or flexed by using a heavy weight to drive the machine (1,000 Gm.). Though there was increased tonicity in the involved arms, the neutral point determined before weights were applied was usually at the same position as found in normal subjects, showing that no contractures were present.

After the usual tracings were taken of one of these subjects (case P27), about 60 cc. of procaine hydrochloride (1 per cent) was injected in the vicinity of the motor points of the arm, as described in Erb's diagram. A few minutes after the injection, the tremor disappeared completely and the tonus diminished. The nerve block was not complete, since the patient was able to move the arm, but the strength was greatly decreased (fig. 9). Tracings were taken of the narcotized arm, and they showed a decrease in tonus and an absence of tremor. The tremor and tonicity returned about forty-five minutes later, as was evident with further tracings.

Four patients with hemiplegia were studied. In three cases the hemiplegia resulted from vascular accidents and in the fourth was caused

by a brain tumor. These subjects all showed an increase in tonicity, but no tremors on the involved side. The neutral points of the arms of these patients were different from those of the normal subjects. In these subjects, the forearm was usually flexed and it assumed an angle of from 45 to 60 degrees with the arm, depending on the extent of the contracture present. When readings were taken by method 1, the tracings characteristically showed the arm quickly flexed or extended as soon as the weight driving the machine was released, and then, after the arm moved a short distance, it stopped abruptly and in many instances even swung back a few degrees. The tracings showed that the paralytic arm actually had little or no tonus at the onset when the arm was first released. Tracings of the subject who had a glioma in the left parietal

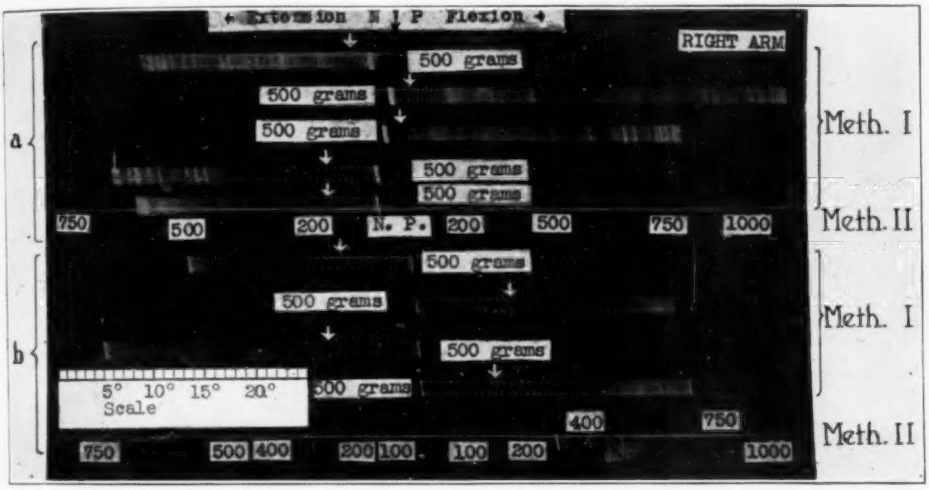


Fig. 9 (case P27).—A man with chronic encephalitis. The tracings taken before ether anesthesia was administered are indicated by *a*, and the tracings taken during anesthesia are indicated by *b*. Note the disappearance of the tremor and the decrease in tonicity ($T = T_o$) (indicated by arrows) during anesthesia.

region were taken shortly before and one month following the removal of the tumor (fig. 10). A temporary flaccid paralysis developed following the operation and then gradually grew more spastic. Readings were taken as soon after the operation as his condition allowed, and he showed much less tonicity at that time than before the operation.

One subject was a boy, aged 12, who had an almost complete brachial paralysis following an injury. He showed a marked loss of strength, with atrophy and atonia in the injured arm one year after the accident. He had practically no muscular power in that extremity. The tracings showed a complete loss of tonus in the arm, for it accelerated throughout the entire excursion and then stopped abruptly because of existing con-

tracture. Repeated tracings were practically identical. Several tracings were taken of the other arm, but they were not satisfactory because of the interference of the subject.

Three subjects who gave irregular tracings were lightly anesthetized with ether, and the tonus was then studied. The tracings became fairly constant while the patients were in this condition, and there was still a measurable resistance in the muscles indicating a decrease but not an absolute loss of muscle tonus. Another patient (case P16) had a hysterical left-sided hemiplegia. This patient was unable to raise her left arm, but her reflexes were equal bilaterally, and no atrophy could be made out. The involved arm seemed flaccid by the usual clinical examination, but by comparing the tracings with the other arm no loss of tonus could be demonstrated. The tracings of the left arm were more constant than the right. This can probably be explained by the patient's practice in relaxation of the involved extremity.

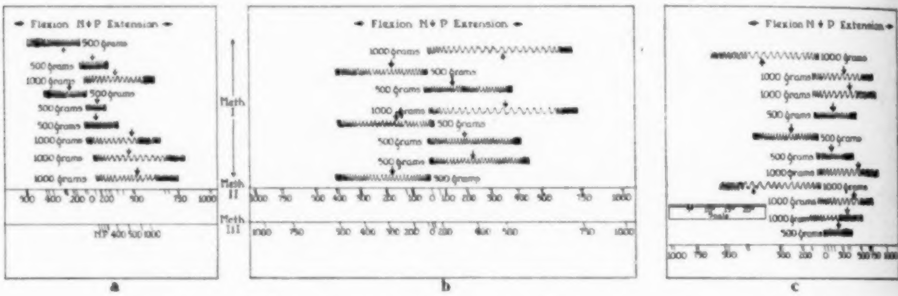


Fig. 10 (case P28).—Traced, not photographed. A man with a parietal glioma on the right. Left arm. Tracings (*a*) were taken one week before operation, (*b*) eight days after the excision of a glioma and (*c*) two months after the operation. Note that the lengths of the tracings in *b* are more regular than those of the tracings in *a*. The patient had practically no voluntary control of his arm at that time, and the tonus in that extremity was markedly diminished. The tracings in *c* show a return of tonus, although it is not as marked as before operation.

Two patients with narcolepsy were studied. Both gave a history of mild attacks of encephalitis. Tracings of one subject were taken at two different sittings while the patient was awake and asleep. Both subjects showed more tonicity when asleep than when awake, but the tracings were more regular in the former condition (fig. 11). Why the tonus should increase during sleep is difficult to explain, but similar observations have been mentioned by Jacobson [6] and others. A further study in this connection is warranted.

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6. Jacobson, E.: Progressive Relaxation, Chicago, University of Chicago Press, 1929.

Tracings were taken of two patients with muscular dystrophy. Both of them showed less tonicity than the normal subjects. Two tracings of the right arm of one of them were illustrated in our previous paper.

One patient with tabes dorsalis (case 12) and one with Friedreich's ataxia (case 14) were studied. Both showed less tonus than the average of the small series of normal cases. Eight cases, including myasthenia gravis, amyotrophic lateral sclerosis and multiple sclerosis, were also tested, but because of the failure of these subjects to relax even with repeated trials, no definite conclusions could be derived from their tracings.

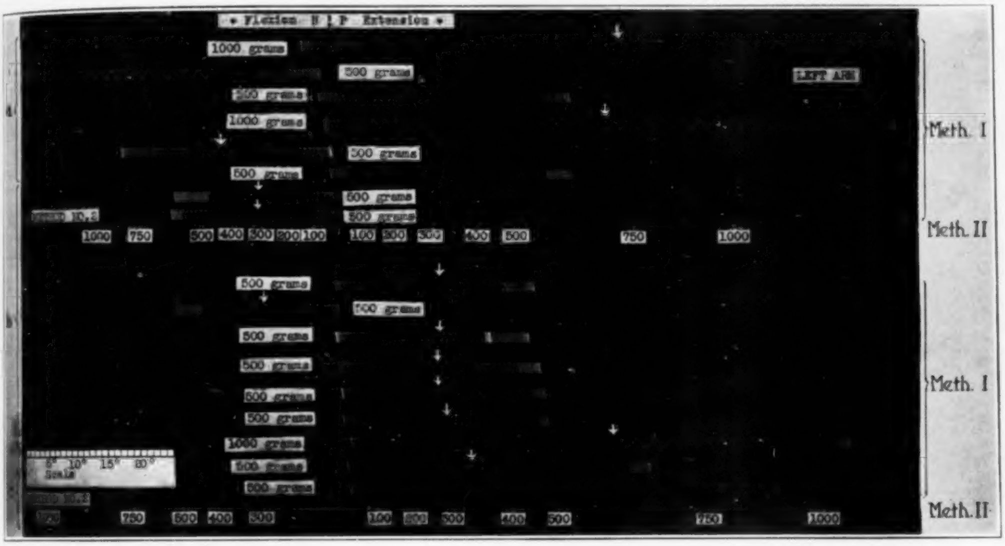

Fig. 11 (case P29).—A man with narcolepsy following epidemic encephalitis. The tracings in *a* were taken by methods 1 and 2 while the patient was awake. Note the variations in the lengths of the tracings, especially those taken in flexion. The tracings in *b* were taken by method 1 while the patient was asleep. They show very little variation. The patient awoke, and the lengths of the tracings again varied (*c*).

COMMENT

Although much has been written on muscle tonus, the knowledge of the underlying neural and muscular mechanisms is by no means complete. Most of the knowledge on this subject has been derived from animal experimentation. It is obvious that information derived from narcotized and nonintact animals cannot give an adequate understanding of this matter. Several workers have devised different types of apparatus to study muscle tonus in man, and the merits and demerits of these machines were briefly discussed in our first paper. It is of interest to

note that practically the only workers who mentioned the difficulty faced in getting their subjects relaxed sufficiently for quantitative studies of tonus were Golla,[7] Betchov[8] and a few others who used the knee jerk method.

The failure of most previous workers to emphasize or even mention the frequent interference of extraneous nervous activity on the part of the subject tested suggests that the method or the apparatus used lacked sufficient refinement for the measurement of such a delicately adjusted phenomenon as muscle tonus. Very slight interferences are magnified by our method, and in our study of eighty-two subjects, we found that over 50 per cent failed to relax satisfactorily.

It is no easy matter for every person to relax well. The clinician discovers this in attempting to elicit knee jerks. Many have difficulty in understanding what the examiner means when he requests them to relax. Dejerine and Gauckler[9] have well stated that, "It is as necessary to have an act of the will to relax a muscle as it is to contract it." Dana[10] has said that, "Thought and emotions are always at once reflected out upon the muscles, which in turn react and return afferent impulses to the brain. . . . The statement is made that 'we think with the muscles' because every thought is accompanied by muscular movement and every muscular movement arouses some feeling." Interesting experiments by Golla[7] have borne out Dana's remarks. For example, he placed a tambour over the neck muscles of a person, and obtained the record of an octave on a smoked drum when the subject reproduced in his mind the notes of an octave. Further studies on the subject of relaxation have been made by Jacobson. Restless, irritable and nervous persons, he said, have "neuromuscular hypertension," and he treats them by training them to relax. From our studies it appears that his term "neuromuscular hypertension" is not satisfactory. Our tracings show that some persons may have difficulty in maintaining constant relaxation, but they are not constantly in a state of increased tension. It appears that their muscular tension actually varies from time to time. During one tracing they may be completely relaxed, while in a following tracing they may show considerable tension and consequently interference. This is often recognized by the subjects themselves, for they frequently announce after a tracing has been taken that they were not well relaxed.

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7. Golla, F. L.: The Objective Study of Neurosis, Lancet **2**:115, 1921.

8. Betchov, N.: Recherches cliniques sur le tonus musculaire, Schweiz. Arch. f. Neurol. u. Psychiat. **2**:3, 1918.

9. Dejerine, J., and Gauckler, E.: The Psychoneuroses and Their Treatment by Psychotherapy, translated by Smith Ely Jelliffe, Philadelphia, J. B. Lippincott Company, 1915.

10. Dana, C. L.: The Anatomic Seat of the Emotions: A Discussion of the James-Lange Theory, Arch. Neurol. & Psychiat. **6**:634 (Dec.) 1921.

It was found that subjects who gave constant tracings the first time practically always gave constant tracings in repeated tests, and those who could not relax at first had the same difficulty in repeated examinations. Obviously, the irregularities occurring in the tracings are due to the physiologic make-up of the subject and not to the method, and one or two sittings constitute a random sample measurement which is nearly as reliable as a long series of data. Observations made on subjects anesthetized or sleeping corroborated these conclusions, for such subjects give constant tracings in repeated trials.

The first of our methods was the most accurate because it was rapid and delicate enough to catch slight tonic changes. The smallest interferences by the subject were apparent in the tracings, and the appearance of the tracings offered a means of judging the validity of the record for a quantitative measurement of muscle tonus, and also indicated the degree of nervous stability possessed by the subject. This method further shows graphically the presence of existing tremors. The second method has an advantage in that there is no sudden pull of the arm which might excite a reflex of the muscles or their antagonists to affect the tracings.

The lag of the "brake phenomenon," which occurs in method 1 and to a less extent in method 3, is almost absent in method 2. Also, excitable subjects have been found to be able to relax better in this method because no sudden pull of the arm disturbs them. It was found that the first method created anticipation to such an extent in some excitable subjects that they found it difficult to relax. The third method appeared to be the least satisfactory, for the subject had too much time to interfere while the tracings were being taken and the lengthening and shortening reactions came into play, vitiating the results. The data appeared more variable in this method than in the other two.

Although my series of pathologic cases is small, repeated observations have given me the following information. In paralysis agitans, in which there is regularly increased tonicity and seldom contractures in the earlier stages, the neutral point is invariably near the 90 degree angle as in normal persons. In hemiplegia it is likewise at 90 degrees, provided there are no contractures. In lower motor neuron lesions (poliomyelitis, for example), when either the flexors or the extensors of the elbow joint are involved, the neutral point is displaced by the unhindered action of the unparalyzed or partially paralyzed muscle group. In sleep (narcolepsy and anesthesia), previously irregular subjects become regular in their tonus measurements. It is interesting to note that deep surgical anesthesia produces little or no decrease in the muscle tonus measurements. In one case a patient showed more tonus in the arm under light anesthesia than when wide awake. Persons asleep are not necessarily

relaxed, as Jacobson has pointed out. Patients with functional neuroses, I found, tend to be much more irregular in their tonus measurements than those who are apparently phlegmatic. A field for a large piece of research is open on this point, though the difficulties are great because of the great variety of neural mechanisms involved which demand analysis.

SUMMARY AND CONCLUSIONS

1. Three different methods were used to measure muscle tonus quantitatively by determining the resistance of resting muscles to passive stretch. These different methods were employed to check the results of one with another and to determine the reliability of each.

2. In the first method used the tonus torque was determined by noting where the positive acceleration of the machine, due to a known driving force, became decelerated by the torques of resting muscles. In the second and third methods, the physiologic resistance of muscles to passive stretch was determined by reading the angular extension or flexion of the arm for varying torques applied. In the second method the arm was swung to and fro by the experimenter, then released and allowed to come to rest at various points where the tonus torque equalized the different known torques of the machine. In method 3 the arm was not swung to and fro, but when the resistance of the muscles equalized one known torque of the machine, that torque was increased and the new resting position of the arm was recorded.

3. It is now possible with a satisfactory degree of technical accuracy to measure human muscle tonus in quantitative terms.

4. A surprisingly large percentage of normal persons show moderate to marked fluctuations in the degree of their muscle tonus, owing, no doubt, to disturbing factors extraneously at play in their central nervous systems.

5. Resting muscle passively stretched has been shown to follow Hook's law reasonably closely—"stress is proportional to strain."

6. The tonus in the right arms of right-handed persons is greater than that in the left. The reverse is true in left-handed persons. Also it was found that men have greater tonus than women. These observations support the theory that tonus of muscle groups is correlated with their strength.

7. Muscle tonus curves become very constant in the sleep of narcolepsy and under the influence of general anesthetics, and may even be greater in degree than during consciousness.

8. The tonus changes in various disease processes as determined by quantitative methods confirm the usual clinical observations.

EFFECT OF LAUGHTER ON MUSCLE TONE

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Laughter may be defined as the manifestation of the combination of bodily phenomena (such as the rapid deep inspiration, the forcible jerky expiration, the utterance of inarticulate sounds, the facial distortion, the shaking of the sides) that forms the instinctive expression of mirth or of a sense of something ludicrous and that can be produced by certain physical sensations, such as tickling.

There are, according to Sully,[1] different kinds of laughter, which may perhaps be classified into two general types: (1) the elementary type, unaccompanied by the perception of the ludicrous or laughable, and (2) forms accompanied by an intellectual discernment of the ludicrous or laughable in the object exciting laughter.

The first type occurs mainly, though not entirely, in children. This type of laughter is seen on tickling, on joy (such as release from restraint, dismissal from school, etc.), on receiving some desired object, at play or during a greeting. This type of laughter, that is, laughter unaccompanied by the perception of the ludicrous or laughable, when it occurs in adults is often not laughter of unmixed joy; it frequently possesses strong overtones of unpleasant emotions; in this category belongs the laughter of triumph, of scorn, of ridicule, of contempt, of superiority and self-congratulation, or more rarely of unbearable pain or of unbearable distress.

The second type, i. e., laughter accompanied by an intellectual discernment of the ludicrous or laughable, is characteristic of maturing or mature persons.

Studies of physiologic changes that take place during the act of laughter are few. Heitler[2] reported that he was once auscultating the heart of a patient who during the auscultation broke into laughter. The heart tones before the laughter were normal; during laughter he found the heart sounds more frequent and irregular, and the second aortic sound was accentuated. After laughter the heart tones became normal. The same writer observed a woman, aged 60, with aortic

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From the Department of Nervous and Mental Diseases, Northwestern University Medical School.

1. Sully, J.: An Essay on Laughter, New York, Longmans, Green & Co., 1902.

2. Heitler, M.: Pulskurve während des Lachens aufgenommen, Centralbl. f. inn. Med. **25**:17, 1904.

atheroma, who following a hearty laugh became unconscious and remained so for ten minutes; during this period the heart sounds were barely audible, and the radial pulse was barely perceptible. The same observer in another instance noted cardiac arrhythmia during the act of laughter.

Until the middle of the last century clinicians did not concern themselves about laughter. Since that time there have come into medical literature descriptions of disorders in which the phenomenon of laughter has taken a prominent place. In the last seventy years, unmotivated laughter has been described in pseudobulbar palsy and in dementia praecox. In recent years, Oppenheim described *Lachslag*, and Gelineau a syndrome consisting of two symptoms, namely, attacks of diurnal sleep and attacks of cataplexy (that is, attacks of partial or complete tonelessness on emotion, especially on mirth and laughter). It was the latter symptom that suggested this study of the effect of laughter on muscle tone.

The earliest conception of muscle tone seems to have been that of Galen (131 to 201 A.D.). He described four varieties of movement, one variety of which was the movement with which, for example, an arm raised to the level of the shoulder is maintained in that position. Galen pointed out that this involves no gross movement, but rather the essence of movement, i. e., static contracture; he called this tonus. Galen, then, really implied that tonus was active posture, a view currently held. Johannes Müller,[3] in 1838, first employed the word tonus as meaning a slight contractile tension characteristic of normal skeletal muscle when at rest. That the maintenance of tonus is a proprioceptive reflex was established by the work of Brondgeest,[3] von Aurep,[3] Mommsen [3] and Sherrington.[3] Sherrington has also shown that there are two great reflex systems in the innervation of the skeletal musculature. One system is the basis of posture, the stimuli being proprioceptive, arising from the labyrinth and the muscles, especially those of the neck (righting and standing reflexes of Magnus and deKleijn). The reflex centers are largely in the medulla and the midbrain. Sherrington and Liddell have shown that the appropriate stimulus for the muscle proprioceptors is stretch. The other reflex system produces phasic or short-lived movements, and its lower level arcs are largely spinal. That there may be extraneural factors in the maintenance of tone was pointed out by Pollock,[4] who stated that tension, elasticity, extensibility, resilience, plasticity, hardness and many other properties are at times used synonymously with tone, and that what relation these properties have to tone is unknown; that none is tone but all may be a part of it.

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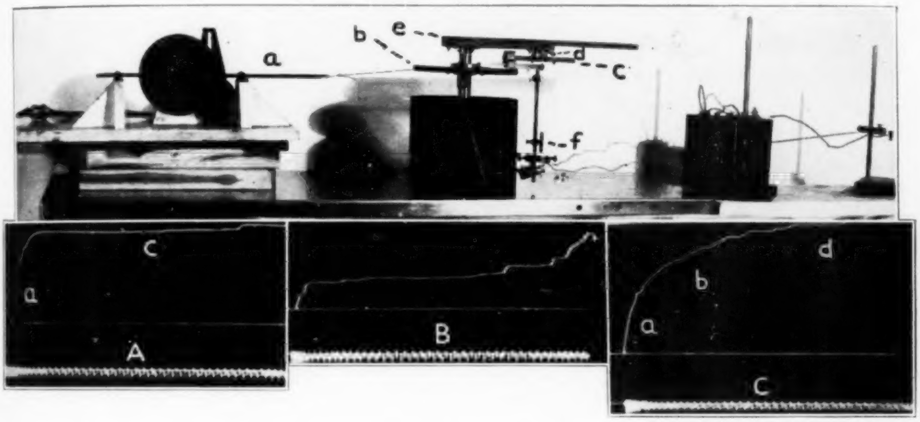
3. Quoted in Fulton, F. J.: Muscular Contraction and the Reflex Control of Movement, Baltimore, Williams & Wilkins Company, 1926.

4. Pollock, L. J.: Muscle Tonus, J. A. M. A. **91**:221 (July 28) 1928.

APPARATUS AND METHOD

The apparatus used in these experiments was devised by Dr. L. C. Hutchinson of the University of Minnesota. His method has not been published, but was demonstrated at a meeting of the Central Neuropsychiatric Association in 1929.[5] The apparatus I used was a copy made from a model kindly furnished by Dr. J. C. McKinley of the University of Minnesota. This method was chosen because it enables one to regulate the speed of the movement; the speed does not depend, as in most other methods, on the speed of falling weights.

The pull in the method used in this study (figure) is produced by a motor, so reduced by means of gears that the shaft (*a*) gives a pull in a straight line, but with a changing velocity corresponding to simple harmonic motion. From the pulling shaft of the motor an inelastic string is attached to the fiber disk (*b*) so that as the pulling shaft goes backward the fiber disk is caused to rotate. At the periphery of the fiber disk is attached one end of a spring (*c*). The other end of the spring impinges on a short metal rod (*d*) attached to the arm-



Apparatus used in the experiments (above). Three tracings (below) taken with the same subject: (*A*) with a calm expression, (*B*) while laughing and (*C*) while frowning. Note the differences in the areas underneath the curve.

board (*e*). The arm-board (*e*) and fiber disk rotate on the same axis, but independently of each other. As the fiber disk is rotated by the motor, it in turn moves the arm-board through the spring. The greater the resistance offered by the arm-board, as, for example, by a weight or by the arm being flexed or extended on it, the greater will be the deflection of the spring, and by this method the amount of deflection of the spring is taken as the indicator of the amount of tone present. For the recording of the amount of deflection of the spring, the framework holding the spring is attached by strings over small pulleys to a disk (*f*) to which a writing lever is fastened in such a way that the lever will rise or fall with increasing or decreasing deflections of the spring. In this way the writing lever, writing on a smoked drum, indicates differences in muscle tone under the varying conditions of the experiments. Below the writing

5. Personal communication from Dr. J. C. McKinley of the University of Minnesota.

lever a time marker is attached. The speed of the pulling shaft in these experiments was one revolution in sixty seconds; the frequency of the time marker was 180 per minute. All movable parts of the apparatus were made as light as possible, and all axles were fitted with ball bearings in order to reduce friction to a minimum.

During the experiment the subject was seated comfortably in a dental chair. The right forearm was placed on the arm-board, in such a way that the forearm made a right angle with the upper arm, and the upper arm made an angle of about 10 degrees with the horizontal. This position was advocated by McKinley and Berkwitz[6] as the one conducive to the most accurate readings. The subject was requested to relax as much as possible, not to resist the movement and not to move voluntarily. All readings in these experiments were taken with flexion of the right arm. The first reading was taken with a calm facial expression. Then the subject laughed. Laughter was sometimes produced by means of an anecdote; in other cases the subject laughed simply on request. In no instance was any considerable amount of mirth present, but it must be remembered, as already described, that not all spontaneous laughter is due to mirth. It was thought possible that the changes in tone seen on laughter were due to the fact that the patient was distracted by his laughter; for this reason control readings with the subject frowning were taken to rule out the effect of distraction. The experiments recorded here were made on fifty normal subjects.

THE TRACING

A set of tracings obtained from a single subject is illustrated in the lower part of the figure. Analysis of these tracings shows that each has certain more or less constant phases. The first part of the tracing consists of a line, which on the tracing appears straight (*a*), but which is in reality a fragment of an arc. This arc represents the upward excursion of the writing lever before lateral movement of the arm has begun; it represents the amount the spring deflected before lateral movement had begun; it therefore is an indicator of the amount of force necessary to start the arm in motion. The length of this line was not constant in each subject, and it was found to be absent in some tracings. Since inertia is purely a mechanical factor and is constant for a given mass, it follows that since this line is not constant in all tracings taken on the same subject, it represents physiologic elements as well as purely physical ones. Following this phase there appears a line in the form of a hyperbola (*b*). The length of this phase also varies. After the hyperbolic phase, the tracings finally show one of two forms. One form is a straight horizontal line, or a plateau (*c*). Sometimes instead of the plateau there is a continuous rise, which indicates a continuous increase in tension (*d*). These phases, it seems reasonable to believe, may be correlated with physical and physiologic properties of muscle and of muscular movement, and will be made the subject of future study and possibly of a future report.

RESULTS OF THE EXPERIMENTS

It was thought that a more accurate method of measuring variations in tonus under the varying conditions of the experiment was to determine differences in the amount of work done in moving the arm a certain distance rather than to judge grossly the height of the curves.

6. McKinley, J. C., and Berkwitz, N. J.: Quantitative Studies on Human Muscle Tone, Arch. Neurol. & Psychiat. **19**:1036 (June) 1928.

Since the area underneath such a curve is an indicator of the amount of work done, the measurement of these areas and their comparison afforded a convenient method for the interpretation of the results. The area measured in each tracing was one resembling a right-angled triangle. The base of this triangle was the base line of the curve. Three

Work Values

Case No.	Work Value During Repose, with Flexion of Right Arm	Work Value During Laughter, with Flexion of Right Arm	Work Value During Frowning, with Flexion of Right Arm
1	2.33	1.45	2.48
2	3.18	1.03	3.75
3	4.17	2.96	6.34
4	3.43	3.10	4.12
5	4.30	4.07	5.06
6	3.53	2.20	3.53
7	2.13	1.81	2.88
8	3.12	1.89	3.17
9	1.93	1.12	2.85
10	2.60	1.42	2.45
11	3.39	2.52	3.86
12	2.50	1.93	1.86
13	2.00	1.38	2.06
14	2.35	1.95	2.53
15	2.38	2.31	2.85
16	1.68	1.52	2.17
17	3.81	3.49	2.89
18	2.90	1.89	1.69
19	1.51	0.58	1.84
20	1.97	1.14	2.22
21	2.57	1.90	3.02
22	1.96	1.25	2.70
23	2.48	1.87	2.49
24	3.32	1.59	4.89
25	2.89	2.25	2.88
26	5.01	2.27	5.97
27	1.52	0.59	2.16
28	3.90	3.80	4.64
29	1.49	1.09	2.12
30	3.42	1.99	6.22
31	2.06	1.27	2.93
32	3.23	2.57	3.17
33	3.65	3.71	3.78
34	2.88	1.78	3.26
35	1.78	1.21	2.90
36	2.42	1.73	2.53
37	1.57	0.98	2.17
38	4.28	3.53	4.19
39	1.38	0.87	1.77
40	2.38	1.66	2.85
41	2.78	2.58	2.58
42	2.04	1.26	3.97
43	3.22	2.72	1.98
44	4.23	3.76	5.47
45	1.80	1.63	2.73
46	3.25	3.11	4.20
47	2.63	3.15	3.24
48	2.74	2.71	3.54
49	2.23	1.70	2.72
50	0.73	0.48	0.97

inches of the base line was arbitrarily chosen because it included all the elements of the curve. The side of this triangle was a line drawn at a right angle to the base line from the base line to the curve. The hypotenuse of the triangle was the tonus tracing; it was irregular in all instances. The areas so delimited were measured with a planimeter, which measured them in square inches. The planimeter readings were taken as an index of the amount of work done, and these readings will

be referred to later as the work values. Variations in the work values represent variations in the total amount of muscle tone measured during a definite time.

The work values obtained for fifty subjects during repose, during laughter and during frowning are shown in the table. The first column shows the work values with the facial expression calm. The values vary from 0.73 to 5.01; the mean is 2.69. The second column shows the work values with the subject laughing. These values vary from 0.48 to 4.07; the mean is 1.99, or 0.7 lower than when the facial expression was calm. In 96 per cent of cases there was a diminution of muscle tone on laughter; in 4 per cent there was an increase. The third column represents the work values in the control group. In this group, readings were taken with the subjects frowning in order to rule out the possibility that the diminution of muscle tone observed in laughter was due not to laughter but to distraction. The work values in this group vary from 0.97 to 6.34; the mean is 3.17 or 0.48 higher than in the group of results obtained with the facies calm, and 1.18 higher than in the group of tracings taken during laughter. In 78 per cent there was an increase of muscle tone on frowning; in 16 per cent there was a decrease, and in 6 per cent there was no change.

CONCLUSIONS

Fifty normal subjects were tested in order to determine the effect of laughter on muscle tone. The movement utilized was flexion of the right forearm. In 96 per cent of cases there was found to be a distinct diminution of muscle tone on laughter; in 4 per cent of cases there was an increase of muscle tone on laughter. An attempt was made to determine whether the decrease in muscle tone noted was really correlated with laughter, or whether the distraction that takes place during laughter was responsible for the diminution in tone. To this end control readings were taken with the subjects frowning. In these controls 78 per cent showed an increase in muscle tone and 16 per cent a decrease, and in 6 per cent there was no change. I believe that in view of these experiments the conclusion may be drawn that there is a diminution of muscle tone during laughter.

RELATION OF THE STATIC AND KINETIC SYSTEMS TO MUSCLE TONE

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The problem of muscle tone is intimately associated with the question of the dual innervation of the striated muscle fiber. Many authorities, notably Sherrington [1] and the English school of physiologists, regard the cerebrospinal innervation as the sole factor in muscle tone. Other investigators confirm the views of Mosso,[2] Grützner,[3] Bottazzi [4] and de Boer [5] that tonus is a function of sarcoplasm under the control of the sympathetic nervous system. This theory implies the existence of both a contractile and a plastic tonus, the latter having the nature of a Sperr or fixation mechanism. Among the investigators who favor this point of view may be mentioned von Uexküll,[6] Ken Kuré,[7] Langelaan [8] and Hunter.[9]

Spiegel,[10] while recognizing a static and kinetic innervation, did not declare himself in favor of separate neuromuscular systems. He regarded these two forms of innervation as of similar nature, differing

Read at the First International Neurological Congress, Bern, Switzerland, Aug. 31 to Sept. 4, 1931.

1. Sherrington, C. S.: Postural Activity of Muscle and Nerve, Brain **38**:191, 1915.

2. Mosso, A.: Sur les functions de la vessie, Arch. ital. de biol. **1**:97 and 291, 1882.

3. Grützner, P.: Die glatten Muskeln, Ergebn. d. Physiol. **3**:12, 1904; **1**:97, 1882.

4. Bottazzi, F.: Theory of the Function of Sarcoplasm in Muscle Tissue, J. Physiol. **21**:1, 1897.

5. de Boer, S.: Die Bedeutung der tonischen Innervation für die Funktion der quergestreiften Muskeln, Ztschr. f. Biol. **47**:239, 1914.

6. von Uexküll, J.: Studien über den Tonus, Ztschr. f. Biol. **60**:334, 1913.

7. Kuré, Ken: Studies on the Dual Innervation of the Diaphragm, Am. J. Physiol. **84**:641, 1928.

8. Langelaan, J. W.: On Muscle Tonus, Brain **38**:235, 1915.

9. Hunter, J. I.: Relationship of Sympathetic Innervation to the Tone of the Skeletal Muscle, Am. J. M. Sc. **170**:469, 1925.

10. Spiegel, E. A.: Der Tonus der Skelett Muskulatur, Berlin, Julius Springer, 1927, p. 78.

only in degree, but would keep the two mechanisms distinct, for the reason that in the higher vertebrates various static and kinetic centers are independent of one another.

Frank [11] has advanced the hypothesis that tonic impulses are conveyed by antidromic conduction over parasympathetic fibers in the posterior roots, a theory that also recognizes the existence of plastic tone.

Perroncito,[12] Boeke [13] and Agduhr [14] expressed the belief that their histologic researches prove that the sympathetic nervous system does participate in the innervation of striated muscle, but those who favor the somatic innervation theory of tonus maintain that the function of the sympathetic is vasomotor and nutritive, and point to the recent investigations of Orbelli [15] to support this point of view. The whole subject of tonus and its innervation, therefore, is extremely complex and far from a final solution.

Some years ago, as a result of investigations of the corpus striatum and cerebellum, I formulated a theory of the dual nature of the whole efferent nervous system. As this conception has a distinct bearing on the question of muscle tone and the existence of separate neuromuscular systems for the control of movement and posture, I venture to review it as a part of this symposium, with certain comments based on advances in knowledge of the past decade.

If separate systems exist at higher levels for the regulation of movement and posture, evidence of similar mechanisms should also be present at lower levels in the phasic and tonic reflexes of the physiologist.

THE DUAL NATURE OF THE EFFERENT SYSTEM

In my theory,[16] which was first formulated in 1920, the function of motility was resolved into two components, each represented by

11. Frank, E.: Die parasympathischen Innervation der quergestreiften Muskulatur, Berl. klin. Wchnschr. **57**:725, 1920; **58**:131, 1921.

12. Perroncito, A.: Études ultérieures sur la terminaison des nerfs dans les muscles à fibres striés, Arch. ital. de biol. **38**: 393, 1902.

13. Boeke, J.: Die motorische Endplatte bei den hoheren Vertebraten, Anat. Anz. **25**:193 and 481, 1909; Ztschr. f. mikr.-anat. Forsch. **8**:561, 1927.

14. Agduhr, E.: Ueber die plurisegmentelle Innervation der einzelnen quergestreiften Muskelfasern, Anat. Anz. **58**:273, 1919.

15. Orbelli: Die sympathischen Innervation der Skelett Muskeln (Wash), M. Sc. Abstr. & Rev. **10**:486, 1924.

16. Hunt, J. Ramsay: The Static and Kinetic Systems of Motility, Arch. Neurol. & Psychiat. **4**:353 (Oct.) 1920; The Dual Nature of the Efferent Nervous System, ibid. **10**:37, 1923; The Static or Posture System and Its Relation to Postural Hypertonic States of the Skeletal Muscles, Neurol. Bull. **3**:207, 1921; Psychic Representations of Movement and Posture: Their Relation to Symptomatology, Arch. Neurol. & Psychiat. **14**:7 (July) 1925.

separate neural mechanisms. One was the kinetic system, subserving movement; the other was the static system, subserving that more passive form of contractility underlying posture and postural tone. There are evidences of a static and kinetic innervation at all physiologic levels of the central nervous system, corresponding to reflex, automatic associated and isolated synergic types of movement and posture. Even in the psychomotor sphere, the functional level for purposive movements, evidences of dual innervation are present.

The Kinetic System.—The primitive motor mechanisms subserving reflex movements are represented in the spinal cord and brain stem and form the archeokinetic systems. The higher motor centers for the control of kinetic function are represented in the corpus striatum and the rolandic area of the cerebral cortex. These are the striospinal and corticospinal pathways of neurology, one subserving paleokinetic and the other neokinetic function.

The corpus striatum, according to this view, is a motor center for the higher control of older types of movement, while the rolandic area is a neokinetic center for the regulation of isolated synergic movements of cortical origin. The paleokinetic system originates in the motor cells of the corpus striatum (pallidal system), and, through its connections with the red nucleus, substantia nigra and other motor groupings of the brain stem, impulses are conveyed by way of the extrapyramidal pathways to the anterior horn cells of the spinal cord. Through its corticothalamic connections this system is in close association with almost all areas of the cerebral cortex.

In striking contrast to this, the neokinetic system is a direct pathway from the cerebral cortex to the anterior horn cells of the cord.

The Static System.—On the other hand, this system is concerned with the transmission of impulses underlying posture and postural tone. The more primitive static mechanisms subserving reflex postures are represented in the spinal cord and brain stem.

The essential integrating and correlating mechanism for the control of the static or posture function is the cerebellum. Afferent impulses from the periphery and efferent impulses from the cerebral cortex pass to this organ before their final distribution by way of the cerebellospinal systems to the myostatic or posturing mechanism of skeletal muscles.

The paleostatic system takes origin in the older nuclei of the vermis cerebelli, while the cerebellar hemispheres regulate the higher postural functions through a neostatic system, which takes origin in the cells of the dentate nucleus. Both systems are under the control of the cerebral cortex by special pathways, the frontopontile and temporopontile tracts.

The chief efferent systems of the cerebellum (paleostatic and neostatic) pass by way of the superior peduncles to the nucleus ruber. From here they descend in the rubrospinal and other systems to the anterior horn cells of the spinal cord, some efferent fibers passing by way of the posterior cerebellar peduncles to the spinal cord.

The distribution of the static system in peripheral nerves, its mode of termination in the muscle fiber and its relation to the sympathetic are still mooted questions and are under active investigation at the present time.

It may be emphasized that all posture systems, neostatic as well as paleostatic, pass to the cerebellum for final integration and control, which is in accord with the nature of the mechanism of posture and its secondary and unconscious rôle in motility. For while the higher forms of movement are initiated as conscious and voluntary processes, the corresponding postures are unconscious and secondary, following automatically in the path of movement. This conception of static and kinetic systems, functioning together in the interest of motion and posture, finds some confirmation in many different fields of research—in histology, physiology, biology, comparative anatomy and neurology.

My earlier communications attempted to lay the foundation for the hypothesis that these two components of motility present a certain parallelism of structure and function at all levels of the efferent system. In other words, that the neural systems of motility, like those of sensibility, may be resolved into more than one component, subserving different types of function corresponding to special adaptations of the organism to surrounding physical forces. For the animal body in its relation to the outer world is in a state of rest or in a state of motion, functions that are subserved by the efferent nervous system and its effector organs.

There are mutual cooperation and harmony of these two systems during muscular activity, a striking evidence of which is reciprocal innervation, which is represented in the muscular activities of both the vegetative and the cerebrospinal nervous system.

According to this view, the static system is concerned with tonic and the kinetic system with phasic activity; each system cooperates to some extent in both movement and posture. The static system contributes to the stability and accuracy of movement; the kinetic system plays a rôle in sustaining posture and attitude. It is the harmonious interplay in the realm of these two systems that underlies the various phenomena of motility.

This anatomic description of the static and kinetic systems was tentative only, and was to be regarded simply as a starting point for further refinements of localization. While these two systems were presented in rather a schematic manner, it was with the full realization of the incomplete and provisional nature of the outline.

The question of static and kinetic components of sensibility in the proprioceptive system was also considered. For if motility is developing along two distinct evolutionary lines in the interest of kinesis and stasis, there must be corresponding afferent systems, and evidence was presented favoring the existence of statesthetic and kinesthetic systems,[17] subserving movement and posture in the sensory sphere. In tabes dorsalis it has long been known that such a selective involvement may occur, causing ataxia without loss of postural tone or well marked hypotonia without ataxia. It was also thought that the existence of static and kinetic divisions of the vestibular mechanism favored a similar point of view for the proprioceptive system.

In the realm of symptomatology there was also much to favor the conception of the dual nature of the efferent system. In general, a disorder of movement implies a kinetic localization and a disorder of posture a disturbance in the static sphere. While both systems participate in any motor disorder, it is often possible to indicate one or the other system as primarily at fault. Among the kinetic manifestations are akinesia, as represented in the different types of palsy, and hyperkinesia, as in fibrillary twitchings, myoclonus, chorea, tremors and convulsive seizures. In the static sphere may be mentioned such disorders as myotonia, catatonia and tonic perseveration, and the essential symptom of cerebellar disorder—the asynergia. The asynergia, according to this conception, is a loss, while the myotonic group represents an increase, of function in the static sphere.

REVIEW OF RECENT CONTRIBUTIONS TO THE TONUS PROBLEM AND DUAL INNERVATION

I shall now review the more important work that has been published since the formulation of my theory, especially that bearing on the problem of tonus and its neural regulation. For while tonus and its innervation have been the subject of much investigation, there is but little unanimity of opinion and a final solution of the problem has not been reached.

The theory of dual innervation of the striated muscle fiber (Perroncito,[12] 1902) is not new. The recent investigations of Boeke,[13] Agduhr,[14] Tello,[18] Dusser de Barenne[19] and Garven[20] have all con-

17. Hunt, J. Ramsay: The Dual Nature of the Efferent System: A Further Study of the Static and Kinetic Systems, Their Function and Symptomatology, Arch. Neurol. & Psychiat. **10**:37 (July) 1923.

18. Tello, J. F.: Genesis de las terminaciones nervioses motrices y sensitivas, Trab. d. lab. de invest. biol. Univ. de Madrid **15**:1, 1917.

19. Dusser de Barenne, J. G.: Once More the Innervation and Tonus of the Striped Muscles, Verhandl. v. k. Akad. v. Wetenschappen **21**:1238, 1919.

20. Garven, H. S. D.: The Nerve-Endings in the Panniculus Caronsus of the Hedgehog, with Special Reference to the Sympathetic Innervation of Striated Muscle, Brain **48**:380, 1925.

firmed the point of view that a single striated muscle fiber is innervated by both a somatic and a sympathetic nerve ending. These investigations disprove the theory of Hunter and Elliot-Smith, based on Kulschitsky's histologic preparations, that red muscle fibers have a sympathetic and white fibers a somatic innervation, a theory that also implied that white fibers are responsible for contractile tonus and red fibers for fixation and plastic tonus.

While some investigators now accept the dual innervation of the striated muscle fiber, a large and important group denies that the sympathetic innervation has anything to do with tonus. Orbelli,[15] of the Pavlov school, expressed the belief that its function is vasomotor and nutritive. He thought that the sympathetic has the same action on the skeletal muscles as on the heart, and that it increases the force and amplitude of the contraction and the rapidity of the development of contraction. He expressed the opinion that the sympathetic controls the vital properties, chemical activities and metabolic exchanges involved in muscle function.

Tonus and Sympathetic Innervation.—Physiologists are divided as to the rôle of the sarcoplasm in the function of striated muscle. Many support the theory of Bottazzi that the rapid contraction, or the twitch, is a function of the sarcostyles under somatic innervation, while the maintenance of tonus is a function of the sarcoplasm, under somatic control. Bottazzi [21] found confirmation of this theory in the slow contraction wave of skeletal muscle when poisoned by veratrine, and assumed that this was produced by separate stimulation of the sarcoplasm. He explained the slow contraction wave of smooth muscle and of degenerated skeletal muscle after denervation in a similar fashion. More recent experimental evidence, derived from the heat flocculation of sarcoplasmic proteins, he also believed, favors this theory of tonic contraction. A reversible heat flocculation of sarcoplasmic proteins occurs at 45 degrees, causing warm contraction, while at 52 degrees warm contraction passes into irreversible heat rigor.

Langelaan [22] for some years has been one of the most vigorous defenders of the sarcoplasmic theory of tonus. He recognized both contractile and plastic tonus, the former somatic and the latter under sympathetic control. In a recent study his previous conclusions, published in 1915, are amplified and confirmed. He stated that contractile tonus is the result of an adaptation reflex by which the length of the muscle is adapted to its tension and for this reason it forms the basis

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21. Bottazzi, F.: On the Alleged Sympathetic Innervation of Striated Muscle, Quart. J. Exper. Physiol. (supp.) **11**:66, 1923.

22. Langelaan, J. W.: On Muscle Tonus, Verhandl. v. k. Akad. v. Wetenschappen **24**:1, 1925.

of coordinated movement. This contractile tonus is independent of the efferent fibers of the sympathetic system. He believed that he has shown the existence of plastic tonus by stimulation of the interoceptive reflex arc during stretching of the splanchnic nerves.

The researches of Kuntz and Kerper [23] also indicate a relation between the sympathetic and plastic tonus of skeletal muscles. They found that the tonus curves of the quadriceps muscles, in cats and dogs, were materially reduced and the brake phenomenon absent after unilateral extirpation of the lumbar sympathetic trunk. Associated experiments on the cerebellum and vestibular nuclei show the importance of cerebellar reflexes as a component of muscle tonus mediated through the sympathetic nervous system. Finally, it was further shown that the tonus of muscle deprived of its sympathetic nerve supply suffers no further reduction following administration of nicotine or removal of the cerebellum and destruction of the vestibular nuclei.

Results quite contradictory to these were obtained by Wastl,[24] who found on stimulation of the sympathetic in mammals no changes in the activity of the muscles that could not be attributed to vasoconstriction. The conclusion was therefore reached that the sympathetic system does not affect the functional activity of striated muscle of either frogs or mammals, apart from its influence over the circulation.

Ken Kuré [25] and his school of Japanese investigators have been active supporters of the sympathetic innervation of striated muscle fibers. He expressed the belief that there is not only a sympathetic tonus, but also a cerebrospinal and parasympathetic tonus. These various systems may act in a compensatory fashion when one or the other is destroyed. Motor tonus is that form which is conveyed to the muscles by the extrapyramidal system and rubrospinal tracts. The centers for motor tonus are in the midbrain, of which the red nucleus is the most important. His conception of parasympathetic tonus follows that of Frank, which invoked the antidromic conduction of the posterior roots. Sympathetic tonus, he believed, is under the control of the cerebellum. Proprioceptive stimuli are conveyed by the tracts of Gowers and Flechsig, the tractus cerebellonuclearis and the labyrinth. The vermian nuclei are chiefly concerned with sympathetic tonus, impulses descending by way of the posterior cerebellar peduncles to the sympathetic cells in the lateral horns of the spinal cord and thence to the muscle by way of the sympathetic outflow.

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23. Kuntz, A., and Kerper, A. H.: Tonus in Skeletal Muscles as Related to the Sympathetic Nervous System, Am. J. Physiol. **76**:121, 1926.

24. Wastl, H.: The Effect on Muscle Contraction of Sympathetic Stimulation and of Various Modifications of Conditions, J. Physiol. **60**:109, 1925.

25. Kuré, Ken, and Shinosaki, T.: Ueber den Muskeltonus, Ztschr. f. d. ges. exper. Med. **44**:791, 1924-1925.

Frank's theory recognized the dual innervation of the muscle fiber, and also plastic tonus as a function of the sarcoplasm. The proof offered is largely pharmacologic and is interesting as offering additional evidence of a duality of function at the neuromuscular level.

In 1920, Frank [11] expressed the view that muscle tonus was under both sympathetic and parasympathetic control—the sympathetic diminishing and the parasympathetic increasing tone. He held that tonic impulses are conveyed antidromatically over parasympathetic fibers in the posterior roots. Much of the evidence is based on pharmacologic experimentation. Frank found that injections of acetyl choline into the tongue after section and degeneration of the hypoglossal nerve will produce tonic contraction in the paralyzed half of the tongue. He inferred from this experiment that choline and the innervation responsible for the tonic manifestation act on the same mechanism. He also found, after degeneration of motor fibers following section of the lumbar and sacral anterior roots, that acetyl choline produced tonic contractions of the paralyzed muscles, and the same results were obtained after section of the peripheral nerves. The phenomenon, however, did not occur if the ganglia of the posterior root were excluded and the sensory fibers were allowed to degenerate.

Ranson [26] investigated this problem, but could find no convincing proof supporting the hypothesis. In conclusion, he stated that:

> The pseudomotor phenomenon, caused by stimulating the sensory fibres after the motor fibres to a muscle have degenerated, has much in common with a contracture caused in the same denervated muscle by acetyl choline, which is a parasympathetic drug with a powerful vasodilator action. Antidromic vasodilatation and the pseudomotor phenomenon are probably both brought about by the fine dorsal root fibres that accompany the blood-vessels. Although the pseudomotor phenomenon and acetyl choline contractures are inhibited by adrenalin, they are not inhibited by large doses of scopolamine and atropine. Hence the pharmacological evidence is against the reactions falling definitely in the parasympathetic class.

Comment: Some recent histologic investigations, therefore, are in favor of the dual innervation of striated muscle. Orbelli has shown that the sympathetic has a definite physiologic action on skeletal muscles of a metabolic nature and not necessarily related to muscle tone. On the other hand, the researches of Langelaan, Kuntz and Kerper and Ken Kuré are definitely in favor not only of dual innervation, but also of the existence of both contractile and plastic tone. Indeed, Ken Kuré recognized both a sympathetic and a parasympathetic tonus. Wastl's experiments, on the other hand, are negative as regards the existence of a plastic tonus under sympathetic control.

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26. Ranson, S. W.: The Rôle of the Dorsal Roots in Muscle Tonus, Arch. Neurol. & Psychiat. **19**:201 (Feb.) 1928; The Vegetative Nervous System, Tr. A. Research Nerv. & Ment. Dis. **9**:394, 1928.

Tonus and Somatic Innervation.—This aspect of the problem has assumed an important position at the present time, owing to the brilliant investigations of the English school of physiology under the leadership of Sherrington. While Sherrington, in his earliest studies, recognized differences in reflex action as phasic and tonic reflexes, he has never accepted the sympathetic as a factor in tonus and the control of sarcoplasm, but maintains that both tonus and movement are under somatic control. Some of the important results of this school of investigation are as follows:

As stretch or myotatic reflexes, Liddell and Sherrington [27] have described a proprioceptive reflex induced by stretching the muscles. The receptors for the reflex arc lie in the fleshy part of the muscle, and the reflex may be evoked by slow, quick and slight degrees of stretch. The reflex increases as the stretch increases, and when it ceases the reflex declines, merging into a plateau-like contraction, which is maintained by the stretched posture component on the stretch movement. This maintained contraction is tonus. When the stretch is applied to a portion only of the muscle, the reflex contraction is also limited to that portion. The reflex is annulled or diminished by reflex inhibition. No trace of a reflex to stretch appears after the afferent nerve fibers of the muscles are cut. Direct stimulation of the afferent nerve of a part of the muscle produces inhibitory relaxation of the stretch contraction in other parts of the muscle. There are among the receptors in the muscles, in addition to those excitable by stretch and provoking reflex contraction, others that provoke reflex inhibition. In most muscles there are two kinds of receptors: those that provoke reflex contraction and others that provoke reflex inhibition. Liddell and Sherrington regarded the knee jerk and patellar clonus as practical examples of the stretch reflex. According to these experiments, the tonus of skeletal muscle is a proprioceptive reflex, a reflex that is graded and controlled by the degrees of stretch. All muscles are not equally sensitive to the stretch; the antigravity muscles give especially good myotatic reflexes.

Eccles and Sherrington [28] have succeeded in reducing the proprioceptive reflex to its ultimate motor unit, consisting of a single ganglion cell and its small packet of muscle fibers. They have determined by actual count the number of muscle fibers in the motor units for various muscles of the cat as well as the contraction value of these units. The

27. Liddell and Sherrington: Reflexes in Response to Stretch (Myotatic Reflexes), Proc. Roy. Soc., London, s.B **96**:*212*, 1924; **97**:*267*, 1925.

28. Eccles, J. C., and Sherrington, C. S.: Numbers and Contraction-Values of Individual Motor-Units Examined in Some Muscles of the Limb, Proc. Roy. Soc., London, s.B **106**:*326*, 1930.

motor unit of the soleus muscle, for example, controls 200 muscle fibers; that of the gastrocnemius 450, and that of the extensor digitorum longus 300. They have also examined the peripheral nerves after degeneration of the sensory elements. In such deafferented nerves they found that the motor fibers are of two sizes, large and small. The small fibers are approximately 4 microns and the larger fibers from 14 to 15 microns in diameter. Both groups of fibers pass through the anterior roots and are unaffected by removal of the sympathetic chain.

In investigating the question of dichotomy they found that the larger fibers are the earliest to divide in their course from cord to muscle, and that such division is seldom encountered among the fibers of small diameter except near their ultimate termination. The large fibers, therefore, tend to form larger motor units; the small fibers form smaller units, the latter serving probably the more delicate adjustments necessary for muscular coordination.[29]

The reduction of the efferent limb of the reflex arc to a single motor unit, which can be isolated for individual study, has already thrown considerable light on the rate of discharge of the anterior horn cells and other peculiarities of the central excitatory state.

It is in terms of these motor units that the reflex fractionates its muscle, and it is now possible by delicate technical procedures to study the function of individual ganglion cells of the spinal cord.

Of peculiar interest to the problem are the investigations of Denny-Brown[30] and Adrian and Bronk,[31] who, working along independent lines, found that tonic responses are maintained at very low rates of discharge, varying from 5 to 15 per second, at which rate a fiber can go on discharging indefinitely, apparently without fatigue. In a phasic reflex, like the crossed extensor reflex, the rate may rise as high as 80 or 90 per cent. This shows clearly that the stronger the stimuli the more rapid the rate of discharge, and it is evident that the rate of discharge is a most important factor in grading the contraction of skeletal muscle.

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29. These striking differences in size and distribution of the motor fibers of the final common pathway lend some support to the existence of neokinetic and paleokinetic representations in peripheral nerves, a theory that I postulated some years ago (Hunt, J. Ramsay: The Existence of Two Distinct Physiological Systems for the Transmission of Motor Impulses in Peripheral Nerves, Brain **41**:302, 1918).

30. Denny-Brown, D. E.: On the Nature of Postural Reflexes, Proc. Roy. Soc., London, s.B **104**:252, 1929.

31. Adrian, E. D., and Bronk, D. W.: The Discharge of Impulses in Motor Nerve Fibres, J. Physiol. **67**:119, 1929.

Denny-Brown's [30] investigation, "The Nature of Postural Reflexes," may be summarized as follows:

The slow regular motor discharge of posture is the result of a central excitation, in which proprioceptive excitation and proprioceptive inhibition are summed with a subsidiary adjuvant excitation, part of which is derived from higher levels of the nervous system. Under especial conditions the central summation itself becomes rhythmic, resulting in the phenomenon of clonus.

In accordance with their threshold of responses to such control, summation of proprioceptive effects, the motor units of a muscle can be graded. The units of lowest threshold grade are present in the red slow extensors and are responsible for the slow tension jerk when central excitability is low, as in the condition of spinal shock. The units of higher threshold grades, according to their grade, require more subsidiary excitation before responding to proprioceptive excitation by discharge. These units are arranged evenly through the different heads of the compound extensors so that the units of highest threshold are confined almost exclusively to the pale muscles.

He expressed the belief that the mechanical phenomenon of postural reflexes can be fully accounted for by motor excitation of the muscles concerned, without the addition of any plastic fixation other than that of the conventional contraction process resulting from excitation, and that the motor discharge in such postural reflexes is a relatively slow repetitive impulse series, thus accounting for their relative resistance to fatigue.

Denny-Brown [32] has also investigated "The Histological Features of Striped Muscle." His findings are so important to the subject under discussion that his conclusions are appended:

In the mammalian striped muscle groups there occur muscle fibres which differ in the speed of the contraction process. The arrangement is such that fibres of similar speed of contraction form a group which is sharply delimited from other groups and in most situations forms a muscle "head" (such as the internal short head of triceps, or vastus externus). In the more complex muscles the deeper heads are those composed of more slowly contracting fibres.

In any such groups of muscle fibres histological differences between the constituent fibres are evident, and occur mainly as differences in content of granules and in fibre diameter. Since the structure of muscle is such that each fibre is able to contribute an effect to the total isometric tension, the occurrence of these histological differences, between fibres of similar contraction process, reveals that these differences have no direct relationship with the speed and nature of the contraction process in the fibre.

The granulation of the striped muscle fibre varies with the nutrition of the animal and appears to be a form of storage of complex substances which can be stained by an alkaline solution of Sudan III.

The fibre groups which retain the primitive slowness of contraction general in the new-born animal retain for each fibre a capacity both for a certain degree of granulation and for a certain degree of enlargement in diameter. Those groups

32. Denny-Brown, D. E.: Histological Features of Striped Muscle in Relation to Its Functional Activity, Proc. Roy. Soc., London, s.B **104**:371, 1929.

which, in the course of growth of the animal, develop a more rapid contraction process, also exhibit a distinction between the processes of granulation and the process of enlargement in diameter; so that in those groups in the adult animal the thick clear fibre and the thinner, granular, opaque fibre are sharply contrasted, the contraction-duration of the two types being the same.

The hypothesis of Grutzner and others that the muscles of higher mammals, including man, are composed of an intimate mixture of fibres of rapid and slow contraction types, being based on their content of clear and opaque fibre, cannot be maintained. These forms, including probably man, possess the same arrangement of fibres in large groups or "Heads" of uniform speed of contraction as do the lower animals, although the differences between one group and another are, at any rate in the monkey, less marked.

The red pigmentation of the slow, less differentiated, muscle fibre also does not appear to be essential to the slow type of contraction process, and is probably the outward sign of some function not clearly related to contraction.

The differentiation of rapid muscles from the slower more primitive muscle affects all the events of the contractile process, so that a twitch in rapid muscle shows the more rapid occurrence of events, in the same sequence as in a twitch in slow muscle. The rapidity also affects the process of summation, so that, while in slow muscle an early second response tends to be augmented mainly in the duration of the contractile process, in rapid muscle such a response tends to be augmented mainly in tension development.

Comment: These investigations of the English school of physiology are of paramount importance and lead the way to a final solution of the complex problem of muscle tone. The stretch reflex is the basis of muscle tone, and it would now appear from the investigations of Denny-Brown that postural function is maintained by slow-contracting red fibers with low threshold for stimuli, while the pale fibers have a high threshold and subserve the phasic activity of muscle function. If these interpretations are correct, there is then, at the segmental level, evidence both histologic and physiologic of special neuromuscular mechanisms subserving postural tone and movement. There are white-fibered units subserving phasic activity and red-fibered units maintaining postural tone, this representing the beginning of that cleavage of function into kinetic and static which I have postulated for the whole efferent system.

Galvanometric Investigations.—These have also played an important rôle in the study of muscle function. Tonus, reflexes and various pathologic conditions were investigated electrically by Wertheim Salomonson [33] in 1921, and appeared to confirm the duality of muscle innervation. Since that time the subject has been carefully studied, with contradictory results.

Hansen, Hoffmann and von Weizäcker,[34] in 1922, investigated tonically contracting muscles in a variety of pathologic conditions—

33. Salomonson, J. K. A. W.: Tonus and the Reflexes, Brain **43**:369, 1921.

34. Hansen, K.; Hoffmann, P., and von Weizäcker: Der Tonus des quergestreiften Muskels, Ztschr. f. Biol. **75**:121, 1922.

tetanus, tetany, spasticity and the rigidity of parkinsonism—and never failed to find evidences of an action current.

The researches of Foix [35] and Thévenard [36] are interpreted as furnishing evidence of a fixing mechanism, which these authors believed to be responsible for spasticity of the muscle. Similarly Lewy [37] has brought forward evidence that a constant deflection of the string is produced when a muscle contracts tonically. He has interpreted this as providing evidence for the dual nature of the muscular mechanism. Adrian, on the other hand, has reached the conclusion that the electromyogram furnishes no support for the dual theory of muscular activity.

In this connection it is interesting to note the findings of Dusser de Barenne [38] that well marked electrical variations of rapid oscillatory character occur during decerebrate rigidity, which shows that tonic muscle does not differ in its qualitative reaction from contracting muscle.

Mann and Schleier [39] also found that passive movements with palpable resistance (tonus) are accompanied by the same action currents as the tetanic voluntary innervation. They concluded that the contraction of tonus and voluntary movement are of the same nature, and that posture and movement are similar, differing only in degree.

Wachholder's [40] electrical studies of voluntary movement and posture yielded similar results.

Fulton and Liddell,[41] from a study of the "electrical response of the extensor muscles during postural (myotatic) contraction," reached the same conclusion. They found that clearly defined electrical responses occur provided the stimulus for the development of the postural reaction takes place with sufficient suddenness to stimulate a large number of afferent endings simultaneously. Such postural reactions are intelligible in terms of one type of contractile response, viz.: the all or none contraction of individual muscle fibers. In conclusion they inferred that these sustained postural reactions are produced by asynchronous—

35. Foix, C.: Réflexes toniques de posture, Rev. neurol. **28**:1130, 1921.

36. Thévenard, A.: Les dystonies d'attitude, Thèse de Paris, 1926.

37. Lewy, F. H.: Die Lehre vom Tonus und der Bewegung, Berlin, Julius Springer, vol. 7, p. 673.

38. Dusser de Barenne, J. G.: Die electro-motorischen Erscheinungen bei der reziproken Innervation der Muskel, Zentralbl. f. Physiol. **25**:334, 1911.

39. Mann, L., and Schleier, J.: Saitengalvanometrische Untersuchungen betreffend den Muskeltonus in normalen und pathologischen Zuständen, Ztschr. f. d. ges. Neurol. u. Psychiat. **91**:551, 1924.

40. Wachholder, K.: Untersuchungen über die Innervation und Coordination der Bewegung mit Hilfe der Aktions-Strome, Ergebn. d. Physiol. **26**:632, 1928.

41. Fulton and Liddell: Electrical Responses of Extensor Muscles During Postural (Myotatic) Contraction, Proc. Roy. Soc., London, s.B **98**:577, 1925.

all or none—contraction of the individual muscle fibers rather than by a hypothetic fixing mechanism.

Comment: Recent investigations with the string galvanometer, therefore, are still somewhat contradictory. Nevertheless, they show that in skeletal muscle tonus and muscle contraction are both registered electrically and differ only in degree. This would appear to indicate that the contractile mechanism of the muscle fiber is functioning in both conditions. It would, however, not disprove the possible existence of "Sperrung" as a possible function of the sarcoplasm.

Reflexes of Posture.—In recent years there have been notable advances in knowledge of the physiology of posture under the leadership of Magnus [42] and his associates, Rademaker [43] and de Kleijn.[44] They have shown that posture is an active process, the result of the cooperation of a great number of reflexes, many of which have a tonic character. Muscular action, especially against resistance, causes fatigue, but tonic reflexes are practically indefatigable and may last for weeks or months, and, according to Magnus, even years. They have shown also that various static reactions, viz., the attitudinal, righting and tonic reflexes, are under the control of centers in the spinal cord and brain stem, and preliminary efforts to localize these postural centers have already been made. Those for the tonic neck reflexes are localized in the two upper segments of the cervical cord; the centers for the labyrinthine reflexes are in the hind part of the medulla, behind the plane of entrance of the eighth cranial nerve, and those for the righting reflexes are situated in the midbrain. Of these the righting centers in the neck extend as far down as the pons and the upper part of the bulb, whereas the other righting reflexes lie at the level of the red nucleus. Rademaker has shown that the red nucleus is the center for labyrinthine-righting reflexes and for body-righting reflexes.

It is apparent from the experimental studies of Magnus and his associates that postural function is compounded of innumerable reflexes under strict coordination, in which reciprocal innervation plays an important rôle. It is also evident that postural function tends to become more and more specialized in the higher levels of the nervous system, and also to become localized in special postural centers.

In the clinical field, reflexes of posture have been subjected to careful analysis, more especially by Foix, Thévenard and Delmas-Marsalet [45] of

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42. Magnus, R.: Physiology of Posture, Lancet **2**:531 (Sept. 11) and 585 (Sept. 18) 1926; Animal Posture, Proc. Roy. Soc., London, s.B **98**:339, 1925.

43. Rademaker, G. G. J.: Expériences sur la physiologie du cervelet, Rev. neurol. **1**:331, 1931.

44. Magnus, R., and de Kleijn, A.: Die Abhängigkeit des Tonus der Extremitätenmuskeln von der Kopfstellung, Arch. f. d. ges. Physiol. **145**:455, 1912.

45. Delmas-Marsalet, P.: Les réflexes de posture élementaires, Tr. Cong. d. med. alién. et neurol. de France et de pays de la langue franç., Lille, July 21, 1930.

the French school. Postural reflexes are the analogs of the lengthening and shortening reaction described by Sherrington in 1897, and have appeared in the literature of clinical neurology under many different names. Westphal's paradoxical reaction, Rieger's "Bremsung," Strümpell's rigidity of fixation in paralysis agitans, the shortening reflex of Wertheim Salomonson and the tonic reflexes of posture of Foix are all similar manifestations in the sphere of postural tone.

Delmas-Marsalet has made graphic representations of the reflexes of posture in normal and pathologic conditions and under the influence of various drugs, which indicate a dissociation of movement and posture function. Thévenard has made an elaborate study of posture under normal and pathologic conditions. A complex postural manifestation, which he termed "le phénomène de la pousseé," is a reflex of attitude induced in the erect posture by a push from behind forward, which produces a contraction of the muscles of the anterior plane of the body, a similar push in the opposite direction inducing a response in the muscles of the posterior plane. Besides these elementary synergies represented by contraction in the anterior and posterior plane of the body, there are other more complex postural synergies, in the production of which the position of the head plays an important rôle.

Comment: These studies in the physiology of posture, both clinical and experimental, show the growing importance of this component of motility under normal and pathologic conditions. In the experimental field the aggregation of postural function in terms of centers is already apparent in the brain stem, and appears to be the forerunner of the complete division that occurs in the static and kinetic systems of the higher levels.

THE STATIC AND KINETIC SYSTEMS AND THEIR RELATION TO MUSCLE TONE

I shall now review the relation of the two systems to the problem of muscle tone in the light of recent investigations.

The division of the great phasic system into paleokinetic and neokinetic was based on atrophy and loss of the motor cells of the corpus striatum in the juvenile and presenile types of paralysis agitans,[46] and while these findings received some confirmation from both French and German sources, it was only recently that van Bogaert,[47] of Antwerp,

46. Hunt, J. Ramsay: A System Disease of Paralysis Agitans Type Characterized by Atrophy of Motor Cells of Corpus Striatum: A Contribution to the Function of the Corpus Striatum, Brain **40**:58, 1917; Primary Atrophy of the Pallidal System of the Corpus Striatum: A Contribution to the Nature and Pathology of Paralysis Agitans, Arch. Int. Med. **22**:647 (Nov.) 1918.

47. van Bogaert, L.: Contribution clinique et anatomique à l'étude de la paralysie agitante, juvénile primitive (Atrophie progressive du globe pâle de Ramsay-Hunt), Rev. neurol. **2**:315, 1930.

in a case of juvenile paralysis agitans, confirmed in every detail the pathologic changes that I described and my conception of this disorder as a primary system disease.

Spastic paralysis and paralysis agitans may therefore be regarded as the two arch types of central palsy, one referable to the pyramidal and the other to the extrapyramidal system. In one there is a loss of the older movements and in the other the more recent motility of cortical origin. With both types of paralysis there is an associated hypertonus, which has distinguishing characteristics, viz., the rigidity of parkinsonism and the so-called spastic state.

In paralysis agitans important motor centers of the brain stem are released from control, while in spastic paralysis the release is at the segmental level of the spinal cord. These differences in the level of discharge explain the differences in the nature and distribution of the hypertonicity in the two conditions.[48]

In my original presentation of the static system the cerebellum was held to be the essential mechanism for the correlation of posture and postural tone.[49] It was regarded as a central ganglion for the regulation of static or posture synergy, in contradistinction to kinetic or motor synergy, which, I maintain, is a function of the kinetic centers. In other words, the cerebellum is a higher integrating center for the control of what at the spinal level is termed postural tone, and is engaged in synergizing the static activities of the organism. While Magnus and his associates have shown that many complex postures and attitudes are localized in the brain stem and occur quite independently of cerebellar control, clinical and experimental neurology shows that the cerebellum is essential to higher activities, and Rademaker's decerebellized dogs show the typical disturbances of cerebellar disorder.

Many other investigations also favor this point of view. Van Rijnberk,[49] who has lately considered the cerebellar problem in all its aspects, reached the conclusion that it is an organ that does not participate in movement as such, but is engaged in maintaining always an optimal tone in skeletal muscles, both during rest and movement. This, I believe, expressed the same general point of view, except that I recognize more specifically the synergizing tonic activities of this organ and its relation to the various physiologic levels of the nervous system.

The experiments of F. R. Miller[50] who, by electric stimulation of the cerebellar nuclei, produced changes in postural tone, both excitatory

48. Hunt, J. Ramsay: A Contribution to the Pathology and Symptomatology of the Cerebellum, Brain **44**:490, 1921; Théorie statosynergique de la fonction cérébelleuse, Rev. neurol. **2**:445, 1927.

49. van Rijnberk, G.: Das Kleinhirn, Ergebn. d. Physiol. **31**:718, 1931.

50. Miller, F. R.: Physiology of the Cerebellum, Physiol. Rev. **6**:124, 1926; Tr. A. Research Nerv. & Ment. Dis. **6**:361, 1926.

and inhibitory in character, are also important. He expressed the belief that the cerebellum is composed of a series of intricate reflex arcs, which in response to streams of proprioceptive impulses from the labyrinths and muscles emit discharges that increase or inhibit postural tone in conformity with the attitude and movements of the body. This study is in harmony with some of the older experimental work of Weed[51] and Cobb, Bailey and Holtz[52] after stimulation of the cerebellum and its pathways in decerebrate rigidity.

Walshe,[53] in a recent discussion of cerebellar function, expressed a somewhat similar point of view when he said that "the cerebellum is the organ through which the cerebral motor cortex correlates the postural components with the phasic components of coordinated voluntary movement." Of course, as posture function is always secondary and the automatic companion of movement, in this sense the cerebellum does correlate the postural with the phasic components of motility, although in saying this I would have it understood that its primary and essential function is the control of postural or statosynergy, which is always secondary to changes in the phasic system.

Among other investigations showing the relation of the cerebellar systems to postural tone may be mentioned those of Ken Kuré.[54] He recognized both a motor and a sympathetic tonus, the former passing by way of the superior peduncles to the motor cells and the latter by way of the posterior cerebellar peduncles to the sympathetic cells of the spinal cord.

Bernis and Spiegel[55] also arrived at similar conclusions in their paper on "Centers for the Static Innervation and Their Cerebral and Cerebellar Control." They regarded static innervation as the source of the station-producing impulses. This arises in the skeletal muscles and labyrinths, passing by way of the posterior roots to the central nervous system, and maintains the upright posture through the medium of spinal and supraspinal reflexes. The influence of the cerebellum is that of tonus regulation, and this takes place not entirely through the anterior peduncles but also by way of a second efferent system in the corpus

51. Weed: Observations upon Decerebrate Rigidity, J. Physiol. **48**:205, 1914.

52. Cobb, S.; Bailey, A. A., and Holtz, P. R.: On the Genesis and Inhibition of Extensor Rigidity, Am. J. Physiol. **44**:239, 1917.

53. Walshe, F. M. R.: The Significance of the Voluntary Element in the Genesis of Cerebellar Ataxia, Brain **50**:377, 1927.

54. Kuré, Ken.: Das Kleinhirn als Regulations Zentren des sympathischen Muskeltonus, Arch. f. d. ges. Physiol. **195**:529, 1922.

55. Bernis, W. J., and Spiegel, E. A.: Die Zentren der statischen Innervation und ihre Beeinflussung durch klein und Grosshirn, Arb. a. d. neurol. Inst. a. d. Wien. Univ. **27**:197, 1925.

restiforme. They also believed from experimental studies on cats and dogs that the frontal and temporal lobes both participate in the control of tonus.

In this connection it is interesting to recall the clinical investigations of Kleist,[56] as well as those of Wilson and Walshe,[57] who have shown the relation of such disorders as myotonia, catatonia and tonic perseveration to the frontopontile system of the cerebellum.

That there are also important independent centers in the brain stem governing movement and posture has been shown in many recent investigations. The anatomic problem is here much more complex, so that at present it is not possible to separate definitely static and kinetic centers in the brain stem, although tentative efforts in this direction have already been made by Magnus and Rademaker in their study of postural function. Tonic neck reflexes are localized in the upper segments of the cervical cord, and centers for the labyrinthine reflexes in the hind part of the medulla. Rademaker has shown that the red nucleus is the center for important righting reflexes, and Spiegel placed the medullary centers for static function in the vestibular nuclei and the large cells of the formatio reticularis.

Therefore, while motor and postural functions are not clearly defined in the complex centers of the brain stem, it may be possible by finer histologic and physiologic methods eventually to separate them. The red nucleus, for example, has connections with both the corpus striatum and the cerebellum and has, therefore, a dual function, which in terms of my conception are phasic and tonic in character, and it is probable that similar divisions are present in other centers of this region. For example, the vestibular nucleus, which receives impulses from both the semicircular canals and the otolith organs, should have both a kinetic and a static representation, corresponding to the dynamic and static labyrinthine reflexes of Magnus. Indeed, it is not unlikely that such distinctions, both anatomic and physiologic, will become more numerous as knowledge of this complex region progresses, thus bringing it more in harmony with the duality of higher levels.

In the spinal cord the problem of dual innervation is still more complex as it involves as well the question of tonus and the innervation of the striated muscle fiber.

SUMMARY

As has already been stated, there are two great schools of thought on this subject. One holds that the dual innervation of the striated

56. Kleist: Ueber nachdauernde Muskelkontraktionen, Arch. f. Psychiat. **10**:95, 1908.

57. Wilson and Walshe: Tonic Innervation and Its Relation to Motor Apraxia, Brain **37**:119, 1914.

muscle fiber is related to a contractile and a plastic tone. The other believes that all contractile functions of the muscle fiber, phasic as well as tonic, are under somatic control, and that the sympathetic function is metabolic, having no relation to muscle tone. The former school favors the theory that plastic tonus is under sympathetic innervation. It admits not only the sympathetic innervation of the striated muscle fiber, but also its relation to plastic tone. Plastic tone, according to its conception is a slow form of muscular contraction, which is related to sarcoplasm and presents the features of a Sperr or fixation mechanism. Indeed, great stress is laid on this latter quality of sarcoplasmic function, the conversion by innervation of a solution into a gel, serving to fix the muscle fiber in its postural relation. It must be said in regard to sympathetic innervation and plastic tone that other investigators working in the same field and by the same methods have had negative results and deny that there is any relation between tonus and the sympathetic system. Frank's theory of a parasympathetic innervation of tonus by antidromic conduction over the posterior roots also recognizes the existence of plastic tone. This theory, in which pharmacologic methods play an important rôle, has not made great progress and Ranson could find no evident support for the hypothesis.

The problem of tonus and somatic innervation has made extraordinary progress in recent years under the aegis of Sir Charles Sherrington and his co-workers. An analysis of the myotatic or stretch reflex, with Liddell, paved the way for the study of the finer fractionation of muscle function and its reduction to the motor unit. With Eccles, the motor units were studied histologically and systematically enumerated for some of the principal muscles of the limbs of the cat. The functional activity of the motor units was also investigated, and a considerable progress has been made in determining the rate of discharge of the anterior horn cells and other peculiarities of the central excitatory state. For it is in terms of these motor units that the proprioceptive reflex fractionates its muscle, and it is now possible to induce discharge and to study one function of individual ganglion cells of the spinal cord.

The work of Denny-Brown in this field is of especial interest in its bearing on the question of postural tone. He has shown that tonic reflexes are maintained at a low rate of discharge, which explains their relative indefatigability, and that the slow red muscle fibers have a low threshold for stimuli and serve a postural function, while the pale fibers have a high threshold and subserve the phasic activity of muscle function. If these interpretations are correct, there is at the spinal level both histologic and physiologic evidence of separate neuromuscular mechanisms for tonus and movement. The white phasic muscle fibers, with

high threshold, produce movement, and the slow red muscle fibers, with low threshold, maintain postural tone, a division at this low level that I maintain for the whole efferent system.

CONCLUSIONS

At the spinal, the prespinal and, above all, the higher suprasegmental levels are to be found evidences of the dual nature of the efferent system.

The great kinetic systems are the well known pyramidal and extrapyramidal pathways. The great static system is represented by the cerebellum and its efferent cerebral and spinal connections.

Recent investigations indicate that the neuromuscular representations of these two great systems are the red-fibered postural and the white-fibered phasic units of skeletal muscle.

The rôle of the sympathetic in the dual function of motility is still uncertain and is an interesting question for the future. For while both tonus and movement are under somatic control, this would by no means exclude the existence of a fixation mechanism of the muscle fiber under sympathetic innervation, a view that is held by many investigators.

SOME POSTURAL REFLEXES IN MAN

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CHICAGO

At a meeting of the Central Neuropsychiatric Association in Chicago on Sept. 27, 1930, a preliminary report was made on a group of studies outlined by Dr. Loyal Davis and Dr. Lewis J. Pollock of the motor responses resulting from neck and labyrinthine reflexes in man, elicited by movement of the head and by caloric and galvanic stimulation of the labyrinths.

This communication deals with an attempt to establish the constancy and pattern of the reaction in the limbs consequent to movement of the head and of another limb in normal persons.

Studies of postural reactions in man, aside from the earlier studies of Magnus and de Kleijn [1] primarily on hydrocephalic and idiotic infants or children, have been reported by Walshe,[2] Simons,[3] Brain,[4] and others. Walshe found evidence of the existence of tonic reflexes of the neck acting on the paralyzed limbs in patients with hemiplegia. Simons, and later Walshe, studied the influence of the position of the head on the form of associated movements in hemiplegia.

Tonic labyrinthine reflexes acting on the skeletal muscles have been studied in normal adult man especially by Wodak and Fischer,[5] who found that suitable normal subjects react with a complex of slow tonic

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Read at a meeting of the Chicago Neurological Society on Oct. 22, 1931.

From the Department of Nervous and Mental Diseases, Northwestern University Medical School.

1. Magnus, Rudolph: Körperstellung, Berlin, Julius Springer, 1924.

2. Walshe, F. M. R.: On Certain Tonic or Postural Reflexes in Hemiplegia, with Special Reference to the So-Called "Associated Movements," Brain **46**:1, 1923.

3. Simons, A.: Kopfhaltung und Muskeltonus: klinische Beobachtungen, Ztschr. f. d. ges. Neurol. u. Psychiat. **80**:499, 1923; Kopfhaltung und Muskeltonus, Neurol. Centralbl. **39**:132 and 256, 1920.

4. Brain, W. Russell: On the Significance of the Flexed Posture of the Upper Limb in Hemiplegia, with an Account of a Quadrupedal Extensor Reflex, Brain **50**:113, 1927.

5. Wodak, E., and Fischer, M. H.: Vestibulare Körperreflexe und Reaktionsbewegungen beim Menschen, Klin. Wchnschr. **2**:1802, 1923. Fischer, Max Heinrich, and Wodak, Ernst: Beiträge zur Physiologie des menschlichen Vestibularapparates. 1. Die vestibularen Körperreflexe und die Fallreaktion. 2. Die Grundlagen und graphischen Registriermethoden der vestibularen Körperreflexe, Arch. f. d. ges. Physiol. **202**:523, 1924.

movements, bringing about a discobolus on unilateral caloric stimulation or on galvanic stimulation of the ear.

Hoff and Schilder [6] have collected and described, in a monograph, a number of purportedly postural reflexes occurring in normal adult man as well as in patients with various focal neurologic lesions. In this monograph, Hoff and Schilder described their basic test. The subject holds the arms outstretched horizontally and closes his eyes. On active or passive turning (rotation) of the head toward one side, the arms deviate chinward at the shoulder joint, the jaw arm usually more so. At the same time, the arm toward which the chin is turned rises steadily. This test is supposed to be positive in from 80 to 90 per cent of normal subjects.

Irish [7] reported the results of a study of the proprioceptive reactions previously investigated by Hoff and Schilder, Weiss,[8] and others. This worker did not consider lateralward deviation of the arm in the application of the basic test, noting only rising and falling of the arms. In his series of fifty-seven normal subjects the incidence of so-called normal responses was considerably smaller than that given by Hoff and Schilder.

Lamb, Portman and Woolham [9] in a brief communication, reported a study of deviations that occur when the arm of a normal subject is held in different positions and changes are induced by the altering of the position of the other limbs or the head, or by labyrinthine stimulation. These workers used a "posture board" in their work, but this apparatus was merely mentioned without further description thereof.

Recently, Bürger-Prinz, Strauss and Kaila [10] made use of large metal arcs, graduated in degrees, placed before the arms to measure the angular deviation of reflex postural movements. The angular displacement at definite intervals of time was noted by an assistant, and the results were charted in terms of angular deviation and time.

6. Hoff, Hans, and Schilder, Paul: Die Lagereflexe des Menschen, Berlin, Julius Springer, 1927.

7. Irish, Cullen W.: Proprioceptive Body Reactions in Topical Brain Diagnosis, Arch. Neurol. & Psychiat. **24**:978 (Nov.) 1930.

8. Weiss, Stephan: Ueber propriozeptive Körperreaktionen in der topischen Hirndiagnostik, Ztschr. f. d. ges. Neurol. u. Psychiat. **118**:167 (Dec.) 1928; abstr., Arch. Neurol. & Psychiat. **23**:55 (March) 1930.

9. Lamb, F. W.; Portman, E. D., and Woolham, G. J.: Posture Deviations of the Arm and Their Reversal, J. Physiol. **65**:x (May 17) 1928.

10. Bürger-Prinz, Hans; Strauss, Alfred, and Kaila, Martti: Experimenteller Beitrag zur Problem der Lagereflexe des Menschen, Arch. f. Psychiat. **92**:334, 1930.

METHOD

It was predicted that the exhibition of tonic postural reflexes acting on the limb in normal man might be facilitated by the elimination of the influence of gravity on the limb, and by the removal of corrective visual impressions. The relaxed subject, with eyes closed, allows the arm or leg to rest suspended from above on horizontally leveled posture boards. The head is then passively rotated to one or the other side, the other limb is abducted and, in the case of the legs, the head is passively turned or ventroflexed. Any resulting deviations of the extremities in a horizontal plane are recorded graphically by an assistant. At the same time, spring balances interposed between the supporting rope and the posture boards allow one to observe any changes in the weight of the suspended lower extremities.

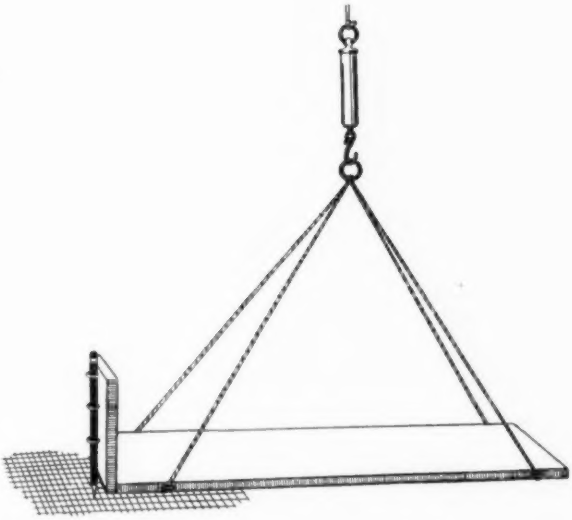

Fig. 1.—Posture board apparatus used in studying responses of arms.

The movements of the arms were studied with the subject seated erect, comfortably, with one arm suspended at one time. In the studies on the lower extremities the subject was placed in the supine position, the trunk and head resting on a level table or couch, with both lower extremities suspended on the boards so as to be conducive to a symmetrically relaxed posture.

The posture boards used (fig. 1) were from 23 to 24 inches (58 to 61 cm.) long and from 4½ to 6¾ inches (11.4 to 17.1 cm.) wide. The pencil carrier is an upright piece of wood attached to one end of the board, fitted with screw eyes placed on a vertical line in order to allow a pencil to slide freely through them in a vertical direction. A Titchenor's automatograph may serve as a posture board. As the arm or leg moves, a pencil recording is made by an assistant who follows the course of the pencil attached to the board. This posture board pencil need not make a mark on the paper, but should serve to indicate the direction of the movement. The tracings were recorded on large sheets of cross-section ruled paper resting on some horizontal surface.

It has been the arbitrary routine in these studies to designate the starting point of movement by a small circle, and to place a cross at that point of the tracing corresponding to the instant when a reversal in the direction of the stimulus movement is begun. If the return excursion is on the same line, a separate parallel line

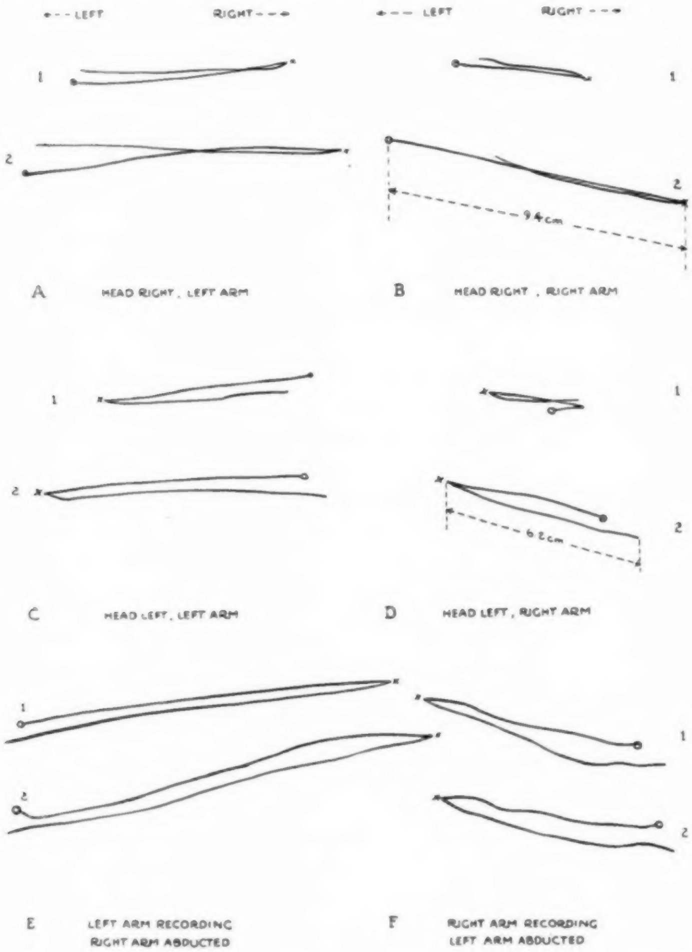

Fig. 2.—Typical reactions of arms in a normal subject, H. J., a man, aged 42. Tracings *B 2* and *D 2* show how the length of the total excursion is measured. In *D 1* is seen the effect of an adventitious phasic reflex causing an apparent initial reversal in the outgoing component of the tracing.

is drawn to indicate the return movement, for a tracing ending at the cross mark is interpreted as showing no movement after reversal of the stimulus movement.

It is to be emphasized in the head-turning tests that the passive rotation should be done fairly slowly, the head being carried to the maximal position compatible with the avoidance of pain and maintained there for several seconds.

MATERIAL

One hundred and four neurologically normal subjects were examined for postural reflexes in the arms and legs. This group included a number of normal persons, such as students and laboratory assistants at the Northwestern University Medical School, but for the most part the subjects were patients at the Oak Forest Infirmary

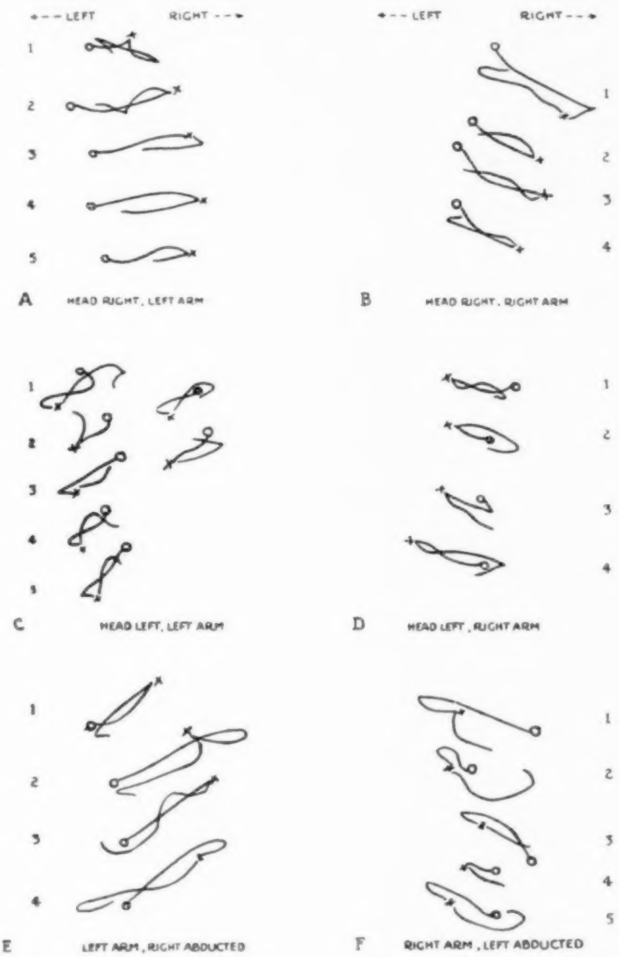

Fig. 3.—Typical reactions of the arms in a normal subject, M. S., a man, aged 42. Note that the laterally deviated resting point of the arm (at the cross mark) is not always at the lateralmost extremity of the tracing. In *C*, the influence of a posteriorly directed component is seen.

of Cook County, Illinois. Most of these, if they were not in the infirmary merely because of destitution, were suffering from heart disease of various types. All of the subjects except ten were men. Inasmuch as most of the inmates at the

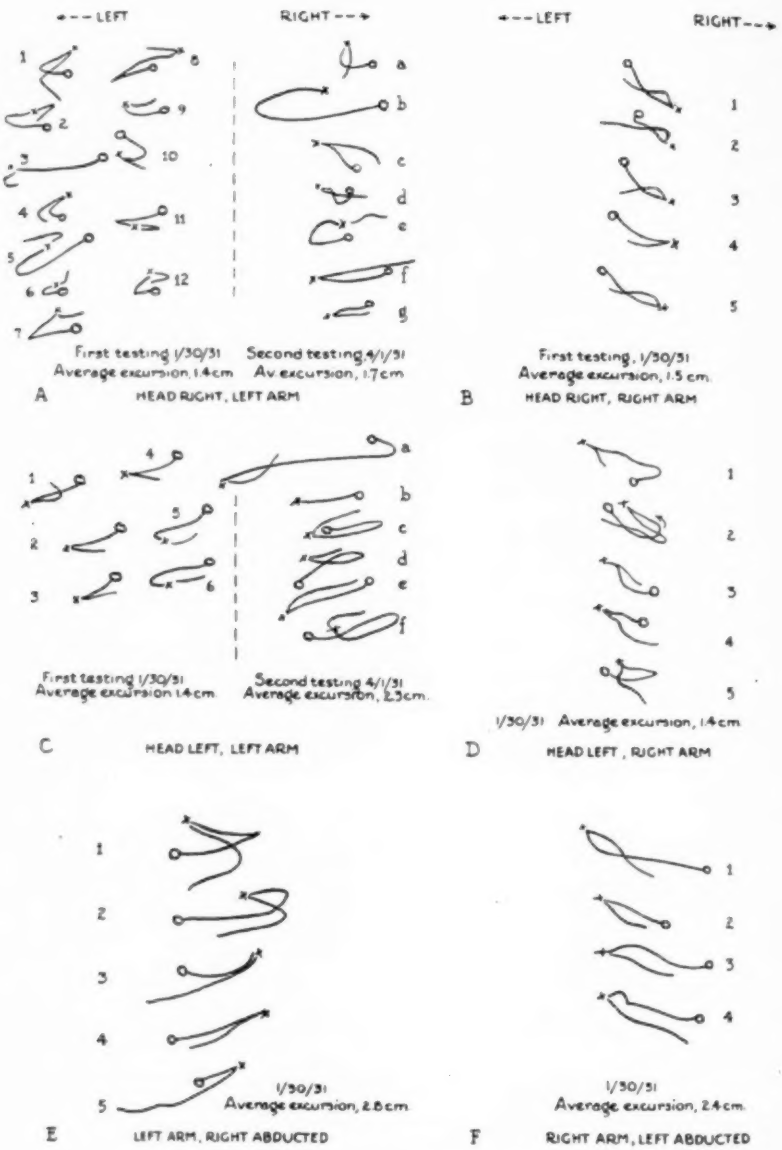

Fig. 4.—Reactions of the arms in a normal subject, J. B., a man, aged 51. In *A*, at the first testing, tracings *3, 7, 9* and *10* represent reversals; *1, 4, 5* and *8* may represent essentially normal tracings complicated by phasic responses; and *2, 6* and *12* are indeterminate forms. On reexamination, *a, c, d, f* and *g*, or five of eight tracings are "reversals." Therefore this set of "head to the right; left arm" responses was considered to show an abnormal pattern, and was included under the classification of "reversal." The responses in *C* and *D* are essentially normal, but the complicating influence of chance phasic reflexes is seen in *C, a, c, d* and *f*, and *D, 1 2* and *5*.

Oak Forest Infirmary are relatively old people, the average age of this group was 51.5 years and the median age, 55 years. The extremes were 20 and 79 years. The standard deviation of this age series was 14.9 years.

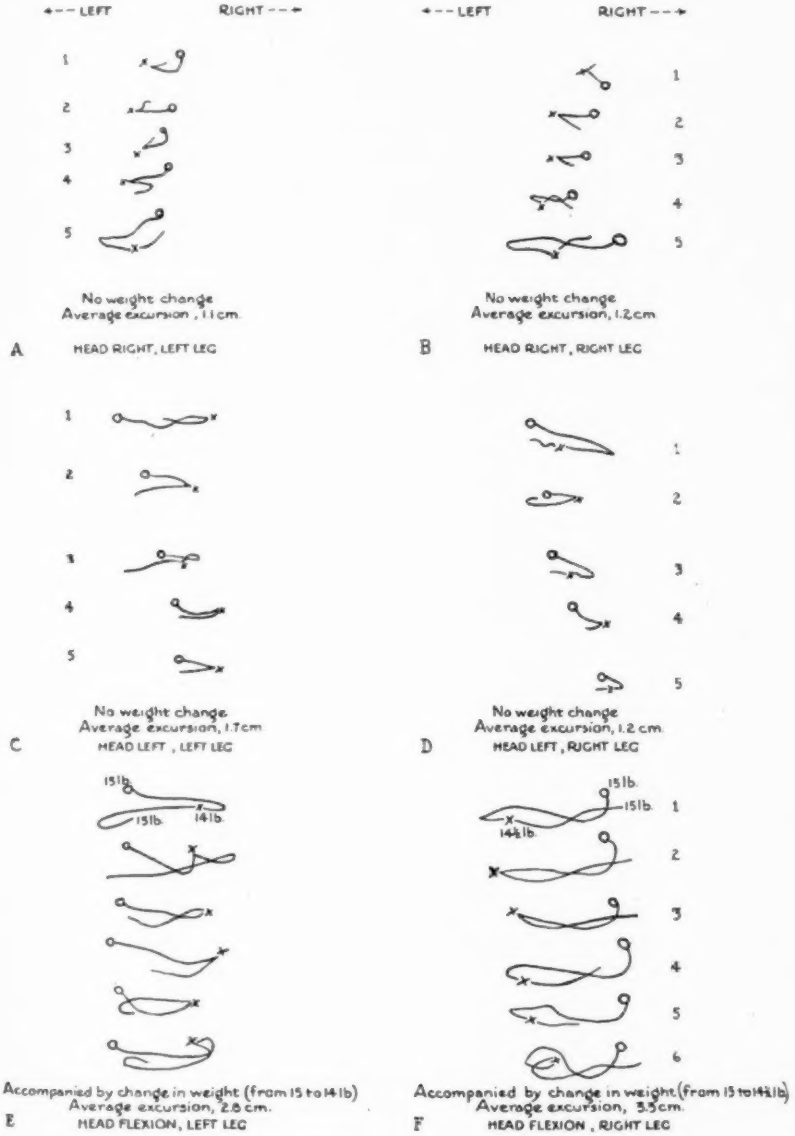

Fig. 5.—Typical responses of the legs in a normal subject, J. A., a man, aged 52.

These patients had no preconceived notions concerning how the arms or legs should deviate, and they represent what one might expect to find in an unselected group of apparently normal persons. On the average, four or five tracings were

made in each case (e. g., head to right, right arm), provided that a normal response was constantly evoked. When the first responses were equivocal or reversed in form, a longer series of tracings was recorded. In the present series, thirty-seven subjects were reexamined at a subsequent date.

RESULTS

The normal responses are as follows:

I. *Reactions of Arm.*—1. With Head Turned to the Right (Chin to Right) with Return to the Median Line: The characteristic response is the same in each arm, namely, a deviation toward the right (chinward), and return on passive rotation of the head back to the midline. The average total excursion in the normal responses for the whole

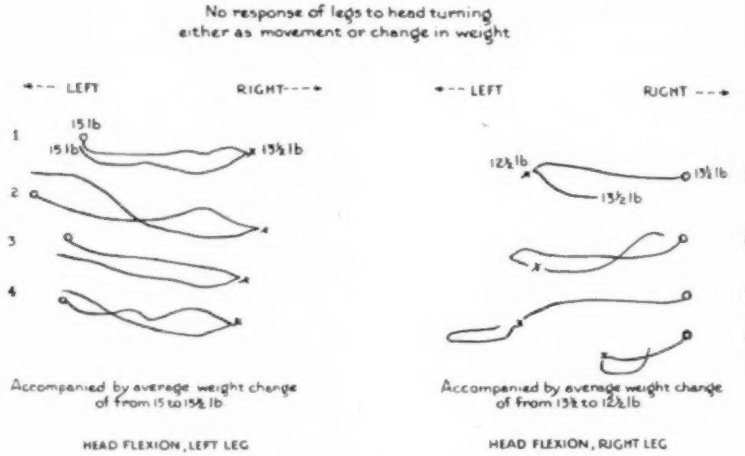

Fig. 6.—Normal responses of the legs in J. B., a man, aged 70. Response only to flexion of the head occurred in about a fifth of the normal subjects tested.

series was 2.5 cm. or 1 degree, 5 seconds of arc. There is an appreciable latent period to the outgo component of the tracing; the head precedes the arm. In a series of forty-three determinations of this latent period, an arithmetic mean and a median value of about 0.6 second each were found. Furthermore, the arm remains deviated toward the right indefinitely until the rotated posture of the head is released. In a minority of cases the deviation of the arm outlasts in time relationship the maximum turning point of the head, the arm continuing to deviate for as much as five or ten seconds, in exceptional instances, after the head has reached the position of maximum rotation and is being held there. In a certain number of these tracings the laterally deviated resting point of the arm is not at the point of maximum deviation of the arm (as in *A 1* and *B 1*, figure 3). Sometimes an apparent

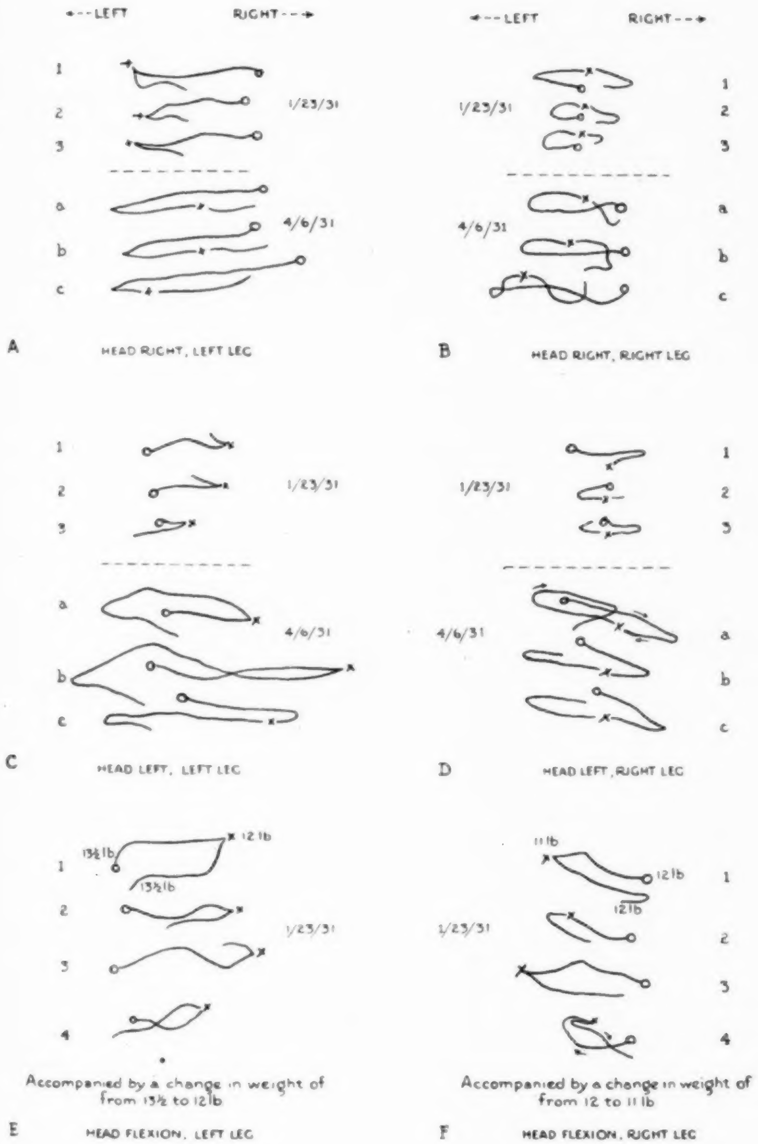

Fig. 7.—Responses of the legs in a normal subject, A. C., a man, aged 56. The responses in *B* are essentially normal, but show an elastic rebound in the first phase of the tracing. In *D*, the small responses obtained in the first testing are somewhat equivocal, but on retesting they appear essentially normal.

initial reversal of direction occurs, which is to be interpreted as an initial adventitious phasic reflex; but usually this is fairly rapid, in contradistinction to the slow movement that follows. The outgoing component (to the right) of these responses is a relatively slow movement, measured in seconds, whereas the return movement is as a rule distinctly more rapid. In the return of the head and arm, these events occurred simultaneously in 56 per cent of a series of subjects in whom this was studied; the average latent period of the return movement (head preceding arm), when it was not 0, was 0.24 second.

2. With Head Turned to the Left (Chin to Left) and Return: Each arm shows a deviation toward the left (chinward) and return on passive rotation of the head to the midline. In general, the same explanatory remarks that were given for the reaction with the head turned to the right apply here.

3. With Right Arm Recording, Left Arm Abducted, and Return; Left Arm Recording, Right Arm Abducted, and Return: The characteristic response is a movement in the direction of the passively abducted arm. This reaction is much more susceptible to interfering mechanical factors (such as the dragging of the whole trunk by and toward the abducted upper extremity); hence, a wider latitude in interpretation of what constitutes a normal tracing is allowed.

II. *Reaction of Legs.*—1. With Head Turned to the Right (Chin to Right) and Return, and with Head Turned to the Left (Chin to Left) and Return: The subject is supine. Both legs deviate in the opposite direction (skullward) and then return on return rotation of the head. The average total excursion is small (from 1.4 to 1.8 cm.). In thirty-five subjects examined, no change in the weight of the suspended lower extremities occurred during the turning of the head, except in two, in whom a slight decrease in weight ($\frac{1}{4}$ pound [0.1 Kg.]) was noted when the head was turned in one direction. The responses are brisker than are the deviations of the arm on turning of the head, and latent period is shorter. The legs, furthermore, more often show a partial return than do the arms. Premature reversals in the form of an elastic or oscillatory rebound are fairly common in the tracings showing very small excursions (0.5 cm. or less).

2. With Flexion of the Head (Ventroflexion of the Head) and Return: Characteristically, the legs adduct and become lighter by about a pound (0.5 Kg.) (tendency toward flexion at the hip joint). The average total excursion is 2 cm. If there is no adduction or other side-to-side movement, no change in weight occurs. The actual decrease in weight, based on sixty-six measurements, averaged 1 pound, with a median value of 0.8 pound (0.4 Kg.). The legs in the boards weighed on the average about 13.5 pounds (6.1 Kg.) while the boards

weighed 2.3 pounds (1.1 Kg.); hence the decrease in weight in the legs was 8.2 per cent.

In the table the results of flexion of the head on the arms are not included because mechanical factors play the chief rôle in this maneuver, obscuring any reflex response. The effect of abduction of the arms on the legs was similarly not included, for the normal response when substantial tables are employed is either no movement or change in weight or merely an indeterminate mechanical oscillation.

The collective survey as revealed by the table corresponds to the behavior in normal individual cases as well. Thus, normal subjects

A Summary of the Postural Responses Obtained in the Series of Neurologically Normal Subjects

	Total Sets of Observations in as Many Different Normal Subjects	Total Sets of Essentially Normal Reactions, Including Those Inconstantly Normal	Predominantly but Inconstantly Normal	Normal on Retrial Only	Indeterminate Type of Response	Reversed Type of Response (Reversal)	No Response	No Change in Weight*	Decrease in Weight of Suspended Leg	Normal Response on First Testing; No Response on Retrial	Average Excursion of Tracing in Cm.
Head to right; right arm	100	100	5	1	0	0	0	—	—	0	2.7
Head to left; left arm	100	94	18	3	1	5	0	—	—	0	2.3
Head to left; right arm	100	92	15	1	4	4	0	—	—	0	2.4
Head to left; left arm	100	97	5	2	0	3	0	—	—	0	2.5
Right arm recording; left arm abducted	100	85	9	0	6	8	0	—	—	0	3.6
Left arm recording; right arm abducted	100	87	5	3	10	2	0	—	—	0	3.2
Head to right; right leg	100	59	1	4	3	0	38	(100%)*	0	3	1.5
Head to right; left leg	100	62	0	5	1	0	37	(100%)*	0	4	1.4
Head to left; right leg	100	62	3	3	1	0	37	(94%)*	(6%)*	3	1.6
Head to left; left leg	100	62	5	0	1	0	37	(97%)*	(3%)*	2	1.8
Flexion of head; right leg	100	77	5	4	2	2	19	1 (3%)*	32 (97%)*	0	2.0
Flexion of head; left leg	100	77	4	8	2	1	20	3 (8%)*	34 (92%)*	0	2.0

* Instances in which weight was observed.

show more indeterminate, less constantly normal and smaller tracings in the skull-arm reactions (H.R., L.A.; H.L., R.A.) than in the chin-arm responses.

The normal subjects may be classified in several groups on the basis of the responses of the legs: (1) those with no reactions of the legs whatsoever (13 per cent); (2) those with response of the legs only to flexion of the head—20 per cent (in exceptional cases, when the graphic response is equivocal a definite decrease in weight may nevertheless be seen); (3) those with responses of the legs to both turning and flexion of the head, possibly only in one direction to which the head is turned (61 per cent) and (4) those with response of the legs to turning of the head (sometimes only in one leg or to one direction of turning) without response to flexion of the head (6 per cent).

COMMENT

In the graphic records this method shows movement only in a horizontal plane, so that whatever flow of tone into the suspended limb is reflexly induced by such stimulus movements as turning of the head is shown only by a lateral (or medial), and to a less extent by an anterior and posterior, component of the resultant movement. When the excursions are small, the vertical or the anteroposterior components may interfere with the normal lateral tendency and cause a scrambled form of tracing. Atypical movements of small amplitude, especially in the tracings for the arms, are to be interpreted with considerable caution.

Chance phasic reflexes may be displayed during the period just preceding the development of the true tonic reflex; these may cause an initial reversed direction in the tracing, a distorted response (tracing *D 1*, figure 2).

Furthermore, these reactions may be inhibited by various conscious and voluntary factors. Only when the subject is more or less relaxed can ideal tracings be expected in normal persons. Retesting is necessary when the first series of responses is equivocal.

SUMMARY AND CONCLUSIONS

1. A method has been described for studying tonic postural reflexes in man.

2. A series of one hundred and four neurologically normal subjects was studied.

3. The normal type of response was found to be an essentially simple to-and-fro design. The arms deviate toward the direction in which the chin points on passive rotation of the head, or in the direction of the passively abducted arm, with return to the resting position on reversal of the stimulus movement. The legs deviate contralaterally to the direction in which the head is turned. On flexion of the head the lower extremities adduct and become lighter.

4. In normal subjects, the incidence of responses of the legs to movement of the head is considerably less than that of the arms.

DISCUSSION

DR. LEWIS J. POLLOCK: Dr. Luhan should be complimented on his industry in collecting the data on this number of cases. An examination of a patient meeting the requirements which he has described is rather a time-consuming task. So many supposed postural reflexes have been described in man, and so many different types have been considered by different workers to be pathognomonic of certain diseases that I think it is important to determine normal reactions. Not only this, but it is important to find some simple reaction rather than to work with all of the complicated postural responses, combined with other mechanisms at times, such as are present in those described by Wodak and Hoff and Schilder.

SPECIAL ARTICLE

MUSCLE TONUS

A CRITICAL REVIEW BASED ON WORK PRESENTED AT THE INTERNATIONAL NEUROLOGICAL CONGRESS, BERN, SWITZERLAND, 1931

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The second morning (Tuesday, Aug. 29, 1931) of the International Neurological Congress was devoted to the tonus of skeletal muscle, the papers being presented by authorities on the subject who were especially invited by the program committee to contribute to the symposium. The chairman (an obvious and perfect choice) was Sir Charles Sherrington, whose remarks helped to bring some order out of the chaos of ideas presented.

ANATOMY

The first paper was by Ranson (professor of neurology at Northwestern University Medical School), the title being "Nuclei and Fiber Tracts Concerned in the Postural Reaction Elicited by Stimulation of the Mesencephalic Tegmentum." His abstract states that stimulation of the mesencephalic tegmentum produces a definite postural reaction—bending of the spine with concavity to the side stimulated, turning of the head to that side, flexion of the ipsolateral forelimb and extension of the contralateral forelimb. This reaction was elicited by stimulation of the region of the red nucleus on the cut surface of the brain stem in decerebrate cats. It was not abolished by section of the decussation of Forel, bilateral section of the dorsal roots of the first three cervical nerves, removal of the cerebellum and of the substantia nigra or bilateral section of the longitudinal fasciculus. After a hemisection caudal to the decussation of Forel, the response could be elicited from the opposite red nucleus but not from that on the side of the hemisection, showing that the impulses are transmitted caudalward without crossing. With an improved model of the old Horsley-Clarke apparatus, the thalamus, mesencephalon and pons were explored with a fine bipolar electrode in lightly anesthetized cats. The reaction, already described, was elicited with threshold stimuli from the posterior (caudal) part of the thalamus

and from the tegmentum of the pons as well as from the mesencephalic tegmentum. At certain points other responses were found superimposed on the typical response, such as erection of hairs, ocular movements, alterations in respiration and a peculiar expiratory cry. Dilatation of the pupils occurred regularly wherever the stimuli were applied. The points stimulated were marked by small electrolytic lesions and the brains prepared for microscopic study, which will be reported later.

This remarkably thorough work brings additional evidence that the lower basal ganglia, the tegmental portions of the midbrain and the upper hindbrain are important for the orderly distribution of muscle tone; [1] in other words, stimuli to these nuclei cause tonic postural reactions of the trunk and limbs. The movements are slow and sustained, quite different from the muscular movements aroused by stimulation of the cerebral cortex. The special nuclear mass involved in Ranson's experiments would seem to be the formatio reticularis which has recently come into prominence as a factor in decerebrate rigidity through the work of Papez,[2] Morgan [3] and others. This is important because the rubrospinal tract in man is so small that it has been difficult to assign to it reasonably all the important postural functions that appeared to be centered in it according to experiments on animals. In man the reticular formation is large, and there is an adequate reticulospinal tract. By considering both the red nucleus (with its rubrospinal tract) and the reticular formation (with its reticulospinal tract) as mediators of the "tonic postural reactions" in man, one has a plausible anatomic basis for the clinical observations.

Graham Brown (professor of physiology at Cardiff) reported experiments on cats in which he stimulated the red nucleus on the cut surface of the midbrain. Earlier work demonstrated the presence of focal points on the cross-section of the midbrain (at the level of the anterior colliculi) in small monkeys and in a chimpanzee. Faradic stimulation of these points, one of which seemed to coincide topographically with the locus of the red nucleus, gave well marked "postural" reactions. These reactions were followed, on cessation of stimulation, by long maintenance of the posture. An interesting observation was the effect produced by stimulation of the corticospinal tract

1. Throughout the first part of this paper the words "tone" and "tonus" are used in the usual loose sense found in medical and physiologic literature. This is because the words are so generally accepted that to eliminate them without a thorough discussion is impossible. Such a discussion will be found at the end of the paper.

2. Papez, J. W.: Comparative Neurology, New York, Thomas Y. Crowell Company, 1929.

3. Morgan, L. O.: The Corpus Striatum: A Study of Secondary Degenerations Following Lesions in Man and of Symptoms and Acute Degenerations Following Experimental Lesions in Cats, Arch. Neurol. & Psychiat. **18**:495 (Oct.) 1927.

against the background of this after-discharge. Even though the cortical reaction and the after-discharge were both flexion in direction, the cessation of cortical stimulation was followed by complete abolition of the after-discharge which would otherwise have been maintained.

Experiments at present being undertaken at Cardiff show that similar postural reactions may be obtained in cats from corresponding areas on the cross-section of the midbrain at the level of the anterior colliculi. By using a new technic, the postural reaction is capable of accurate study. Stimulation of this area on one side of the cross-section gives turning of the head toward the same side with the whole vertebral column bent convexly to the opposite side, to such a degree that the hip of the animal is sometimes brought into contact with its face. This posture is accompanied by flexion of the foreleg of the same side and the opposite hindleg and extension of the two remaining limbs. The claws were sometimes protruded, and there was usually rapid breathing; salivation sometimes occurred, and the hair on the tail might be erected.

The posture thus assumed may long outlast cessation of stimulation, but often suddenly disappears. Graham Brown thinks that the whole question of posture suffers to a certain extent from its nomenclature, and that it might be worth while to consider the adoption of a new standard nomenclature.

A brief report of former experiments on the pathways of muscle tonus and their endings in muscle by Prof. Ken Kuré of Tokio brought up the question of sympathetic innervation of striated muscle. He believes that there are three kinds of "tonic innervation" in voluntary muscle: cerebrospinal, sympathetic and parasympathetic. The evidence presented, however, was simply more of the kind that has been carefully examined and rejected by Tower after histologic work on both nerve endings [4] and muscle structure [5] and by Wilkinson.[6] (This aspect of tonus will be further discussed later.)

These three papers were the only anatomically oriented contributions, and the first two were based on experiments with stimulation. Graham Brown worked with Sherrington during the exciting years when decerebrate rigidity was being investigated and used as a background for studies of the spinal reflex. For the last ten years he has been interested in mesencephalic reactions. This work of elaborating Sherrington's fundamental contributions led to the important researches of Magnus and his collaborators of the Utrecht School, who worked on the vestibular mechanism, and of Rademaker, who has published a comprehensive monograph on the red nucleus and another on cerebellar mechanism.

4. Tower, Sarah S.: J. Comp. Neurol. **53**:177, 1931.

5. Tower, Sarah S.: Bull. Johns Hopkins Hosp. **48**:115, 1931.

6. Wilkinson, H. J.: J. Comp. Neurol. **51**:129, 1930; M. J. Australia **2**:768, 1929.

PHYSIOLOGY

It was unfortunate that Rademaker (professor of physiology at Leyden) was unable to attend the Congress and present his paper on "Les facteurs régularisant le tonus musculaire." His abstract, published in the Congress booklet, shows that he classifies muscle tone as normal tonus, hypotonus or hypertonus; the latter is not an augmentation of tonus but the continuation of muscular contraction under circumstances in which it would normally be abolished. Rademaker believes that muscle tone is determined by: (1) labyrinthine stimulation; (2) exteroceptive stimuli (excitatory or inhibitory); (3) proprioceptive stimuli evoked by muscular stretch (excitatory or inhibitory), and (4) afferent impulses from the eyes, ears and different internal organs. All these factors influence the amount of tone present in a muscle. From the standpoint of anatomic localization the centers in the medulla oblongata are the only ones that produce hypertonus; supramedullary influences are not necessary; the red nucleus normally has a controlling influence on extensor tone that is exhibited if the medullary centers are acting alone; the cerebellum also has an inhibitory relation to muscle tone. No experimental proof is available that the striatum has an influence on tonus. It is as yet unproved that the sympathetic nervous system has any rôle in producing muscle tone. Such a brief statement from Rademaker is important, even though it adds nothing new to his published views, for his beautiful experimental technic is well known and his conclusions should be accepted as superseding much of the earlier work which was less extensive and less accurately executed.

Along this line an important paper was published in abstract by Denny-Brown of London, who was unable to attend the Congress. Briefly reported, the results of these researches on "The Part Played by Afferent Muscular Nerve-Endings in Postural (Tonic) Reflexes" are: The afferent muscle receptors for the reflex arc producing decerebrate rigidity are tension receptors stimulated by either active or passive tension. Active muscular contraction, apart from the stimulation of these receptors, also stimulates a proprioceptive inhibitory afferent system which serves to control the heightened tone which the contraction tension would otherwise produce. In this way the reflex differentiates between active and passive tension in the muscle. The adjustment of tension according to length (lengthening and shortening reactions) is the result of control of the active muscular tension (muscle tone) by the inhibition it produces. The resulting tonic reflex is a purely spinal process, and is influenced by brain stem and other reflexes by the addition of either excitation or inhibition to the equilibrium which the spinal reflex attains.

This is important work, showing as it does the rôle of the lowest integrative levels in the spinal cord on postural reflexes. The implication

is clear that muscle tone is looked on as a proprioceptive postural reflex with various levels of control: spinal, medullary, mesencephalic and perhaps higher.

L. J. Pollock (professor of neurology at Northwestern University Medical School) and Loyal Davis (assistant professor of surgery, Northwestern University Medical School) read a paper "On the Relation of Modifications of Muscle Tonus to the Interruption of Certain Anatomical Pathways." They have taken up the important consideration of the physical properties of muscle in the light of the work of such investigators as Hill, Gasser, Levin and Wyman. Their new contribution is concerned with reporting the results of measuring "momentum curve" and the "hysteresis curve" of normal, hypertonic and hypotonic muscles. The observations were made by using specially devised machines to measure the tension developed and the movement performed by the forelimb of man and animals.

The time allotted to present this complicated subject was inadequate, and before any evaluation of the work can be made the complete data must be presented. Pollock and Davis' statement, however, that "The lengthening reaction is common to the muscles of decerebrate animals and is not dependent upon any proprioceptive muscle reflex" seems rather radical in the light of the extensive researches of the Oxford physiologists, and one awaits their evidence with interest.

Von Weizsacker (professor of neurology at Heidelberg) presented a method that may become useful and convenient for measuring muscle tone by determining the chronaxia of the muscle, which apparently has a relationship to the tonic abnormalities that are found following supranuclear lesions.

Professor Kroll and Dr. Markow (of Minsk, U. S. S. R.) also reported on "Muscle Tonus and Chronaxie." They measured the chronaxia of muscle under many conditions, some of which were related to tonic changes. For example, after corticospinal lesions the chronaxia was reduced, especially in the extensor muscles, while in the flexors, which were not hypertonic, the chronaxia was increased. The hypotonic muscles resulting from some cerebellar lesions also show a reduced chronaxia. In hemiplegic patients the chronaxia of the extensor hallucis in the affected leg is greater when the patient is lying prone than while lying supine. In lesions affecting the ventral horn cells and causing muscular weakness and atrophy the chronaxia is usually increased.

Frédéric Bremer of Brussels discussed the pharmacology of muscle tone. He stated that muscle tone is fundamentally a tetanic contraction of skeletal muscle innervated by the cerebral nervous system and dependent on myotatic reflexes. Thus, pharmacologic agents can cause variations in muscle tone by acting on (1) the sensory end-organs in the muscle ("atonie novocainique" caused by injecting procaine hydro-

chloride into the muscle) and (2) the motor myoneural junction, as in partial curarization. In the latter case tone is decreased even in spastic muscles, but tendon reflexes remain. Epinephrine administered intravenously will momentarily reestablish the rigidity abolished by curare, because epinephrine has the power to remove for an instant the block at the myoneural junction. Bremer believes that these observations invalidate the theory that striated muscle has a sympathetic innervation.

CLINICAL EVIDENCE

There were four clinical papers. Prof. A. Donaggio of Modena presented evidence from cases of encephalitis to show that the frontal cortex is connected with the substantia nigra and that there is a "tonic" function of the pyramidal as well as of the extrapyramidal tracts. Dr. F. Negro of Turin also discussed extrapyramidal syndromes. He speculates on a residual "bio-electrochemical" tonus after removal of the influence of the central nervous system. Moreover, he harks back to the theory that sympathetic fibers innervate the sarcoplasm of the muscle—a mere surmise of Botazzi's which has never been seriously considered by physiologists.

Kinnier Wilson (London) stated that from a clinical standpoint tonus can be disordered in consequence of lesions at four levels: (1) spinomuscular; (2) midbrain cerebellar; (3) basal ganglia; (4) cortical. Experimental physiologists, working with animals, have never been able to produce clinical pictures familiar to every neurologist. The clinician sees phenomena never seen by the physiologist, for the clinician studies a neuraxis not artificially mutilated. The principles of the hierarchy of levels have been learned by the clinical method. Such phenomena as the toneless collapse of a patient in a cataplectic attack or the similar fall of a man knocked out by a blow on the chin are worthy of study. In the first case the precipitating shock is emotional; in the other it is obviously physical. Furthermore, Jacobson [7] has shown that one can voluntarily inhibit knee jerks by learning to relax completely the quadriceps muscles. Hemitonia apoplectica and its converse—focal attacks of flaccid paralysis—indicate that there is a "cortical representation of muscle tone."

These clinical observations are important, but it seems self-evident that in a "hierarchy of levels" the higher levels control the lower; the more complex integration controls the less complex. A sustained standing reflex from the vestibular nuclear level must be broken into by the cortical innervation that (for example) sends down orders for unilateral movements of one forelimb. The concept of reflex integration would seem to do away with such unwieldy dualistic concepts as "representation" of muscle "tone" at each level of integration.

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7. Jacobson, E.: Am. J. Physiol. **96**:115, 1931.

SYMPATHETIC INNERVATION

The question of the sympathetic nervous system and its relation to muscle tone was brought into the lime light when Ramsay Hunt (professor of neurology at Columbia University) read his paper, "The Static and Kinetic Systems and Their Relation to Muscle Tone." He reviewed his well known conception of the dual nature of the efferent motor system, in which he holds that motility is subserved by two separate neural mechanisms: a kinetic for the control of movement and a static for the regulation and maintenance of tonus and posture. There are evidences of a kinetic and a static innervation at the spinal and supraspinal levels, but the exact pathways underlying these two functions (phasic and tonic) are still under investigation. At higher levels the differentiation between the two systems is well defined; the kinetic system is represented by the corticospinal (neokinetic) and striospinal (paleokinetic) systems.

This theory has been acceptable to many neurologists and helpful in understanding motor function, but when Hunt states that the "dual innervation of striated muscle is now generally accepted" he slides out onto thin ice. In 1920, one of us [8] answered this same theory, propounded at a meeting of the American Society for Clinical Investigation, by saying that:

> Hunt's explanation of muscle tone depends on accepting as a fact the sympathetic innervation of skeletal muscle. This rests on the work of three men: (1) Boeke, an anatomist, who demonstrated sympathetic nerve endings in skeletal muscle. This has been corroborated by other workers. (2) deBoer, a physiologist in Amsterdam, whose experiments indicated that section of the sympathetic nerves decreased muscle tone. These experiments have been repeated by two workers who were unable to substantiate deBoer's findings. (3) Langelaan, whose paper is largely a theoretical analysis of the work of others, and whose conclusions have not been corroborated. The theory of sympathetic innervation of skeletal muscle is an attractive one, because it explains so many now inexplicable phenomena of muscle physiology. We have no right, however, to build theories until the basic physiologic facts on which they stand have been substantiated. I believe that the relationship of muscle tone to sympathetic innervation is still unproved.

Since that time the discussion has become polemic, reaching its acme in 1925, the year following Hunter's fateful trip from Australia. At that time Walshe [9] gave an excellent review of the facts, and considered sympathetic innervation unproved. Now Wilkinson,[6] Hunter's successor in the chair of anatomy at Sydney, has come out with a complete denial of the validity of the whole theory of sympathetic innervation of skeletal muscles, and even explains the anatomic findings of Boeke on

8. Cobb, S., in discussion of Hunt, J. Ramsay: Static and Kinetic Components of Efferent Nervous System: Their Function and Symptomatology, J. A. M. A. **78**:1661 (May 27) 1922.

9. Walshe, F. M. R.: M. Sc. **12**:437, 1925.

a nonsympathetic basis. Hinsey [10] and Hines [11] have also been unable to substantiate the anatomic work of Boeke, and many reliable investigators have failed to support the findings of deBoer [12] and Langelaan,[13] whose early contributions gave Hunter and others the idea of explaining muscle spasticity and other tonic phenomena on the basis of a dual innervation of the muscle. Tower [4] began a convincing paper with:

> Weight of evidence has overborne the once stimulating concept that there are exhibited by mammalian skeletal muscle two modes of contraction, phasic and tonic, served by separate nervous mechanisms, somatic and sympathetic, and perhaps by muscle fibers of distinctive character.

In conclusion she said:

> Without exception, every ending seen on a skeletal muscle fiber was formed either by a myelinated nerve fiber or by a non-myelinated branch of such, and degenerative section demonstrated the somatic motor origin of these fibers. Endings of sympathetic nerve fibers or of non-myelinated fibers of independent or untraceable origin were in no instance observed. Muscular and vascular innervations were separately derived from the larger intramuscular nerve trunks and at no point communicated in their peripheral distribution. Constancy characterized the innervation of the limb muscles.

In 1925,[14] one of us discussed fully and negated the theory of sympathetic innervation, concluding that: "Tonus is a beautifully graded series of proprioceptive reflexes, continuously and unconsciously playing its part in our every motor act. By its remarkable specificity it moulds our individual muscles; by its universality it controls our postures." Hunt apparently agrees with this conception and realizes the importance of Sherrington's contribution when he says:

> These investigations of the English School of Physiology are of paramount importance and lead the way to a final solution of the complex problem of muscle tone. The stretch reflex is the basis of muscle tone and it would now appear from the investigations of Denny-Brown that postural function is maintained by slow contracting red fibers with low threshold for stimuli while the pale fibers have a high threshold and subserve the phasic activity of muscle function.

These new investigations by improved methods have made untenable the older theories. Formerly it was held that the lack of action currents in spastic limbs and other tonically contracting muscles indicated a special catch mechanism that allowed the muscle to hold a position without electrical or metabolic change. Some authors even described artefacts in their electromyograms as "sympathetic waves." All this was considered evidence favoring the theory of sympathetic innervation. The recent

10. Hinsey, J. C.: J. Comp. Neurol. **44**:87, 1927.
11. Hines, M., and Tower, S. S.: Bull. Johns Hopkins Hosp. **42**:264, 1928.
12. deBoer, S.: Ztschr. f. Biol. **61**:239, 1915.
13. Langelaan, J. W.: Brain **38**:235, 1915; **45**:434, 1922.
14. Cobb, Stanley: Physiol. Rev. **5**:518, 1925.

work of Dusser de Barenne, Adrian, Liddell and Fulton [15] makes obsolete the earlier investigations quoted by Hunt and annihilates these arguments.

In spite of all this new evidence, Langelaan (professor of pathology at Baarn, Holland) presented a paper at this Congress reporting hypotonia of the hindleg in frogs when the rami communicantes were cut at the lumbar level. This report appears to be a restatement of observations published by him in 1922,[13] and the observations are similar to those published by deBoer in 1913. As already noted, these findings are not yet substantiated, and many authors deny their relation to a sympathetic innervation of skeletal muscle. Newton,[16] in fact, has explained the weakness of the sympathectomized leg as being due to trauma to the lumbosacral plexus. He developed an operative method which allowed the sympathetic to be removed without the operator even touching the motor nerves to the leg. In animals thus operated on there was no difference between the tonus of the two legs. The immediate loss of reflexes reported by surgeons after "ramisection" is probably explainable in this way.

HUMORAL INFLUENCES ON MUSCULAR CONTRACTION

Another type of investigation briefly reviewed for the Congress by Professor Asher of Bern has yielded more consistent results. A word on the background of this and other communications may indicate the general trend of thought in this field. Through Orbeli, Baetjer and Asher it has been demonstrated that, in addition to any other function the sympathetic may have, stimulation of the sympathetic nerve supply of a contracting muscle may delay or overcome fatigue. This is true for both cold and warm blooded animals.

Asher discussed chiefly the work done in his institute during the past few years (Maibach, Labhart, Charlet, Michel and Veser). These workers used the frog and, by means of an improved technic, first confirmed the observations and conclusions of Orbeli, namely, that stimulation of the sympathetic nerves to a limb has the effect of increasing the height of contraction of skeletal muscle showing evidence of fatigue after repeated or prolonged contraction. Then through experiments not so convincing as those of Baetjer [17] they demonstrated that such improved effectiveness was not entirely due to an increase in the blood supply of the muscle, and also that similar effects could be produced by immersing the contracting and fatiguing muscle in weak solutions of epinephrine.

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15. Fulton, John F.: Muscular Contraction and the Reflex Control of Movement, Baltimore, Williams & Wilkins Company, 1926.

16. Newton, Francis C.: Am. J. Physiol. **71**:1, 1924.

17. Baetjer, A. M.: Am. J. Physiol. **93**:41, 1930.

To determine the site of action of the sympathetic, Asher's students then performed the following interesting and suggestive, but inconclusive, experiments. In curarized frogs it was observed that after fatigue had set in through repeated stimulation of the muscle itself, stimulation of the sympathetic again restored contraction of the muscle or increased its height on direct stimulation, whereas stimulation of the spinal nerve to the muscle still produced no contraction. From this it was concluded that the sympathetic effect could not be said to be due to restoration of the "end-organ." Further, the lower thoracic region and hindlegs of the frog were perfused with a calcium-free solution of sodium chloride. The thesis was, that since such a calcium-free perfusate prevented contraction when single induction shocks were applied to the nerve but allowed contraction when the nerve was tetanized, it might be possible, if the sympathetic acts on the "end-organ," so to alter the latter through the effects of stimulation that even single shocks would produce a contraction if applied immediately after the sympathetic had been stimulated. Since no such contraction was produced it was concluded that the sympathetic effect was on the muscle itself rather than on the "end-organ."

Finally, through less involved experiments on spinal decerebrate and intact frogs, the Swiss physiologists were convinced that the height of repeated reflex contraction reached a lower level sooner on the sympathectomized side than on the side not operated on. From this it was concluded that the effectiveness of the skeletal muscle was increased through the action of the sympathetic.

Two questions at once arise: Do not such effects necessitate the anatomic connection of sympathetic nerve and striated muscle? If not, how does one explain the observed phenomena?

Experiments by Loewi and Cannon and more recent observations reported at the Congress by Hansen (Heidelberg) threw light on these questions. As far as the heart is concerned, certainly anatomic contiguity does not seem essential. This has been shown by Loewi [18] for cold blooded animals and confirmed by Hansen for warm blooded animals. The former noted that stimulation of the vagus branches to the heart causes the fluid contained in the heart chamber to be so altered as to be capable (if removed during the period of stimulation) of stimulating the initial action of the vagus on the same or another heart when later introduced into its chambers.

Hansen, employing as a test object the pregnant guinea-pigs, demonstrated electrocardiographically that whenever the vagus was stimulated in the mother there was a decrease in her heart rate which was followed by a similar if less striking decrease in the heart rate of the fetus. The effect was relatively independent of changes in the oxygenation of the blood reaching the fetus.

18. Loewi, O.: Arch. f. d. ges. Physiol. **214**:678, 1926.

Moreover, such effects are not limited to vagus stimulation, as was also shown by Loewi.[19] He observed that when the accelerans to the frog's heart was stimulated the fluid contained in the chamber of the heart during the period of stimulation was altered in such a way as to make it capable, if then removed, of stimulating the effect of direct sympathetic stimulation on the same or another heart when it is introduced into the chambers. Further, Cannon noted that stimulation of the sympathetic in the caudal portion of the cat caused the denervated heart in the same animal to beat more rapidly, although all afferent nerve pathways to the heart had been surgically removed. One is again forced to conclude that the blood, in passing through the tissue supplied by the stimulated sympathetic, is so altered that it causes a rapid beat when it enters the heart, thus resembling the action of direct sympathetic stimulation (at least as far as rate is concerned).

In other words, it is not unreasonable to suggest that the fluid passing through the blood vessels of skeletal muscle during the period of sympathetic stimulation is so altered that the enhanced effectiveness described may result. It remains now to ask, What is the nature of this alteration in the fluid passing through the region in which the sympathetic is being stimulated?

Loewi,[18] who first described the effect of stimulating the accelerans on the fluid in the chamber of the heart, postulated the liberation of a substance into the fluid which has a dynamic effect on the test heart. He noted its similarity to epinephrine. It is of interest that the effect of sympathetic stimulation of fatigued muscles is not very different from that observed by Cannon[20] some years ago when he exposed fatigued muscle to the secretion of the suprarenal glands or epinephrine. Cannon also explained his more recent experiments,[21] in which stimulation of caudal sympathetics was followed by acceleration of the denervated heart, by postulating the discharge into the blood stream of a substance, not unlike epinephrine, which he has provisionally called "sympathin." Whether these are all identical and what, indeed, is the nature of this substance, are still to be determined definitely.

It is of interest that a similar observation was made on man by Altenburger.[22] He determined the rate of onset of fatigue on repeated contraction of the muscles about the upper lip through stimulation of the facial nerve after one-sided removal of the cervical sympathetic and observed that evidence of fatigue appeared sooner on the side on which the operation was performed than on the opposite side. This provocative observation needs to be repeated for confirmation.

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19. Loewi, O.: Arch. f. d. ges. Physiol. **143**:201, 1922.

20. Cannon, W. B.: Bodily Changes in Pain, Hunger, Fear and Rage, New York, D. Appleton and Company, 1929.

21. Cannon, W. B., and Bacq, Z. M.: Am. J. Physiol. **96**:392, 1931.

22. Altenburger, H.: Ztschr. f. d. ges. Neurol. u. Psychiat. **132**:490, 1931.

In summary, then, incorporating the facts brought out at the Congress with those already known, one may say that it is probable that sympathetic nerves do not end in striated muscle, but that stimulation of the sympathetic nerves to the vessels of a muscle may alter the tissue fluid or blood in such a way as to change the muscular contractility. For example, sympathetic stimulation enables skeletal muscle, especially with the onset of fatigue, to contract for a longer period and more forcibly. This is in harmony with the function of the sympathetic throughout the organism, which in broad terms of physiologic economy may be thought of as a means for furthering the development or liberation of reserve energy.

REFLEX INTEGRATION

All this discussion of sympathetic innervation is interesting and important, for it drives the last nails into the coffins and prepares for burial the corpses of the theories of dual innervation, sympathetic innervation, sarcoplasm contraction and the like. It does not, however, tell one what "muscle tone" is. The difficulty seems to be with the word "tone." Its use as applied to skeletal muscle is inexact and confusing. It connotes a different sort of contraction of muscle, and thus is misleading. Muscular contractions differ in degree and speed, but not in essential mechanism. From the point of view of mechanical result there are several kinds of muscular contractions. One may cause a quick, isolated, purposeful movement of one limb ("kinetic"); another contraction may cause a slow, bilateral change of posture; a third may simply maintain a posture ("static"). The neurologic mechanisms concerned with bringing about these different types of mechanical movement resulting from muscular contraction are extremely complex, but recent studies are rapidly elucidating the problem. Ramsay Hunt's concept of "kinetic" and "static" gave impetus to considerable thought, and Kinnier Wilson's clear statement of the "old motor system and the new" cleared up many problems. But to Magnus, whose early loss we grieve, and most of all to Sir Charles Sherrington one owes the concept of reflex mechanisms of different types causing muscles to contract cooperatively in such a way that the result may be skilled volitional movement, complex automatic movement, unconscious postural movement or maintenance of posture. No clear line separates one from the other. All work together to give unified bodily motility.

With Hunt's conclusion, that one finds at all levels evidence for the dual nature of the efferent system, we would take sharp issue. The motor system is not to be looked on as dual, triple or quadruple. According to the situation, more or fewer reflex units are integrated to produce an adequate response. The resulting movement, for example, may be a slow change of posture involving spinal reflex arcs, reflexes of the lower medulla oblongata, the vestibulospinal tract and righting reflexes from the red nucleus. Such a movement is no better understood by being

called "static" and "tonic" because it is a slow motion with change of position. Any oversimplification is misleading: dividing the motor system horizontally into an "upper motor neurone" and a "lower motor neurone" has caused confusion because it does not fit the anatomic facts. The same may be true of the vertical division into "static" and "kinetic" systems. It seems to us much better to accept the fact that the central nervous system is complex, to learn as much anatomy and physiology as one can and to understand thus as many integral parts of a movement as possible, realizing, however, that the whole movement is an integrated reflex response.

Hunt said in one place: "Tonus, reflexes and various pathological processes were investigated electrically." Here is an excellent example of the confusion arising from the use of the word "tonus," as if to indicate a special sort of contraction in skeletal muscle. Tonus is the result of a reflex, just as much as a quick muscular contraction that shows movement. Changes in posture are reflexes, and are usually classed as due to tonic innervation. Certain automatic movements, however, such as those concerned in coordinating the trunk, legs and arms when rising from a chair or sitting down, are in an unnamed middle ground.. The automatic movements of walking are considered "phasic" and not "tonic." Every one would consider the unilateral skilled movements of the right hand as phasic, not tonic. The question is, Where should one draw the line? Furthermore, we question whether any line ought to be drawn. It leads to better understanding and clearer thinking if muscular contraction is named simply and objectively; some types are, for example, isometric, do not cause movement; there is contraction that causes slow postural movement, automatic associative movement, rapid automatic movement, and so on up the integrative scale to the most refined, skilled movements of the fingers. But it must be remembered that at each level of integration all the lower levels are incorporated and aid in the movement. Thus it is not a question of "tone following movement like a shadow"; it does not follow, for it is not separate from movement. The simpler reflex forms of muscular contraction are integral parts of the more complex movements; the complete volitional movement includes all levels; "tonus" is as much a part of the motor act of dancing as a muscle cell in the quadriceps is a part of the extensor muscles of the leg.

Hunt admitted that: "It is quite apparent from the experimental studies of Magnus and his associates that postural function is compounded by innumerable reflexes under strict coordination." It is equally apparent, we believe, from the work of Sherrington, Forbes and others that locomotion, scratching and any movement one wishes to analyze are a "compound of innumerable reflexes under strict coordination." Then it becomes impossible logically to draw the arbitrary line between movement and posture, and the distinction between "static" and "kinetic"

vanishes. Hunt's "complete division which occurs in the static and kinetic systems of the higher levels" seems to us impossible from all we know of integration.

CEREBELLUM

Recent literature is full of arbitrary classification; it is the natural outcome of the rapid development of neurology. Generalizations made in advance of adequate observations are often helpful for a time, but must be disregarded when fuller understanding shows them to be no longer accurate. Thus, van Rijnberk,[23] in his recent review of cerebellar functions, tried to dissociate movement from "tone" by saying that the cerebellum does not participate in the coordination of movement, but maintains optimal "tone" in skeletal muscles during movement. Such distinctions seem to us misleading.

If "tone" flows into a flexed limb following decerebration, the limb is slowly extended to the typical extensor rigidity posture. To say that one mechanism causes the movement and another supplies the "tone" is wrong in even so simple an example. It is even more incredible that the cerebellum can control only "tone" and not participate in movement, when postures are the essential basis from which movement must start.

Schematically, it may be said that the postural centers of the basal ganglia, midbrain and medulla give the basis from which to start voluntary movement; postural influences hold the body erect, appropriately placed in respect to the center of gravity, and allow such motor activity as walking without waste of conscious effort. The cerebellum coordinates (synergizes) the higher voluntary and the lower automatic mechanisms. It takes the body as it finds it at any instant and interprets in an effective and orderly way the orders from the cortical headquarters.

We agree with the clear summary of Walshe [24] when he says that "the cerebellum is an organ through which the cerebral motor cortex achieves the synthesis of coordinated units which go to make up voluntary movements"; however, we do not think he improves the definition when he adds that "the cerebellum is the organ through which the cerebral motor cortex correlates the postural components with the phasic components of coordinated voluntary movement." It is drawing too sharp a line between "postural" and "phasic."

There has been much discussion about the relation of the cerebellum to "tone." Recently, the theory that "hypotonia" explained cerebellar symptoms has been losing prestige; Weisenburg [25] said that "hypotonia" is not a symptom of cerebellar lesions. Holmes,[26] discussing cerebellar function, still holds that "defect of tone can explain some of the dis-

23. van Rijnberk, G.: Ergebn. d. Physiol. **31**:719, 1931.

24. Walshe, F. M. R.: Brain **50**:377, 1927.

25. Weisenburg, T. H.: Brain **50**:357, 1927.

26. Holmes, Gordon: Brain **50**:385, 1927.

orders of movements." Confusion results unless it is understood that what Holmes means by "defect of tone," in this case, is a defect in the postural reflexes which maintain fixation of the limbs at their more proximal joints. The point is that these terms have masked the essential: an understanding of the integration of muscular contraction into purposeful movement. The element of postural fixation is a fundamental muscular function for most human movements. This simple reflex pattern has been well explained by Sherrington, Magnus, Rademaker and others as a function of the brain stem. When, however, the cerebral cortex comes into play, there must be coordination of all the simpler forms of muscular contraction with the complex. The cerebellum supplies this coordination (synergia).

Phylogenetically, however, there is an old part of the cerebellum closely related to the vestibular nuclei which may have a closer relation to standing and other postural reflexes. This paleocerebellum [27] lies mesially, surrounding the roof nuclei. Injury to this part of the cerebellum seems to cause a vestibular symptomatology (changes in head posture, decreased standing reflexes and nystagmus). The vestibular nuclei, however, are so near that it is probable that they are usually injured by the same lesions, the symptoms being directly caused by lesion of the vestibular mechanism. Indeed, when the cerebellum is carefully removed there is no "hypotonia" [28] and the vestibular reflexes are increased. This appears to be due to the destruction of the fastigiovestibular bundle, a tract from the roof nuclei to the vestibular nuclei in the medulla. One might say that the cerebellum "inhibits the tonus" of decerebrate rigidity. It seems to us clearer and more specific to say that the cerebellum, by controlling the standing reflexes via the fastigiovestibular and cerebelloreticular tracts, can coordinate this postural activity with the more complex movements integrated in the midbrain and forebrain. Much of this work is new and not yet corroborated. Nevertheless, as a working hypothesis, it is useful to remember that the paleocerebellum is closely related to the vestibular nuclei, and that the neocerebellum is related to the cerebral cortex (it is developed only when the cerebral cortex is well developed, and functions with it, according to Walshe's hypothesis and Fulton's experimental work).[28]

Lesions of the paleocerebellum cause interference with standing reflexes, postural reflexes and automatic ocular movements. Lesions of the neocerebellum, on the other hand, cause dyssynergia of the more highly integrated movements related to the cerebral cortex; for example, an inability to write because of loss of synergia in the hand. Past pointing, by contrast, is due to injury of the older vestibular mechanism or

27. Ingvar, S.: Folia neurobiol. **11**:205, 1918.

28. Fulton, J. F.; Liddell, E. G. T., and Rioch, M.: The Relation of the Cerebrum to the Cerebellum, Arch. Neurol. & Psychiat., this issue, p. 542.

even of the vestibular end-organ. These distinctions often cannot be made clinically, for a lesion injuring one part of a small organ like the cerebellum, lying as it does enclosed in the posterior fossa of the skull, almost always affects other parts of the cerebellum and brain stem by pressure.

In this brief discussion of cerebellar function it is obvious that confusion has arisen because of the vague use of the word "tone," a word used by physicians to indicate anything from mild psychologic euphoria (supposed to be induced by "tonics") to a specific reflex pattern of muscular tension.

CONCLUDING COMMENTS

Sir Charles Sherrington has allowed us to include in this review his own words as spoken in closing the discussion at Bern. As always, they are graceful words full of meaning and stimulation:

Our meeting on Tonus may congratulate itself on having received a valuable series of contributions, to its various aspects, and from various sources. The contributions have been the more valuable because those who made them dealt with their own first-hand observations. I regret that pressure of time should have curtailed the period available for individual speakers. As to anything to add, so much ground has been covered that I feel little remains which I can add.

One impression remaining with me from our discussion is that the relation of the sympathetic to the tonus of skeletal muscle although it has now occupied especial attention for several years is a subject which especially calls for further investigation. The account given us by Professor L. Asher of the observations made here in Bern by his pupils and himself offers particular interest. It is valuable because its clearness is of itself convincing, and it extends as well as confirms the observations of Orbeli which are not easily accessible to us. The influence, functionally traced, of the sympathetic to skeletal muscle is lacking still, it seems to me, a corresponding anatomical basis. It is a problem urgently requiring further investigation.

A point which has been relatively little touched upon in our discussion today, and yet it always seems to me remarkable and striking in laboratory experience of skeletal-muscle tonus, is the much greater prominence and ease of exemplification of postural tonus in extensor muscles (antigravity muscles) than in flexors. In the laboratory we have still no reliable way, apart from the use of drugs, by which to obtain a good tonic or hypertonic flexor preparation. The qualities of the postural tonus of the flexor muscle are therefore relatively little known. Questions which are natural to ask about it remain still without answer. Does it require for its maintenance the afferent nerves of the flexor muscles themselves? Is it reflex, and proprioceptively reflex? Does the tonus of the flexor muscle like the extensor muscle give evidence to reflex excitation arising from the receptors of the muscle itself (autogenic)? Again, does the flexor like the extensor give evidence of self-inhibition reflexly developed from the receptors of the contracting muscle itself (autogenic inhibition) e. g., lengthening reaction? I fancy there is no evidence at present that the receptors in flexor muscles differ from those in extensor muscles (certainly there are muscle-spindles and Golgi-organs in both); so far as I know the afferent nerve fibers of the flexor are as numerous and of the same appearance as those of the extensors. Yet of the proprioceptive reflexes of the flexors including tonus itself little is known as compared with what is known for the tonus of the

extensors. The latter have their autogenic self-excitation, and their autogenic self-inhibition, reflex mechanisms which together go far to explain the postural behaviour of the extensor reactions.

One broad trend I think becomes evident in the tonus-question at the present time, and it is that the problem of the nature of tonus has already fundamentally simplified itself. The gap between tonus and kinetic contraction is less wide than it was. Tonus is static contraction; and static contraction and kinetic contraction are seen more and more clearly to rest upon the same essential rhythmic activity of muscle, nerve and nerve-centre. The nervous impulses and contraction waves which maintain both are quite similar and are discharged by the same motor-horn cells (motoneurones) and travel by the same path. In tonus it is true their frequency is lower; and hence they can be maintained for long periods without fatigue. Also, the percentage of motor units engaged out of the total which compose the reacting muscle is usually smaller in tonus than in phasic contraction. Further there are certain muscles, all of them extensors (antigravity muscles), which tonus (reflex-postural tonus) employs by predilection, so to say, though it is far from confining itself to them; these are the so-called "red" or slow muscles. More characteristic of them than their "redness" is their relatively slow contraction-waves. These muscles, e. g., the soleus, might almost be called "tonus-muscles." But here again the difference between the action-currents and contraction waves in them and in ordinary muscle is merely quantitative, not qualitative.

Indeed tonus-contraction appears to be a milder and simpler form of ordinary contraction, not differing otherwise than in intensity from the contraction of ordinary kinetic reflexes and indeed of voluntary acts. The tonus-contraction process in the muscle-fibers was once thought to be something of different nature from the contraction-process for ordinary reflex and voluntary movements. It is true that on the whole the tetanic rate of firing of the motor unit in tonus is of low frequency and considerably lower than in ordinary reflex contractions. But both in tonus and in other reflexes the rate of tetanic "firing" in the individual motor units varies from time to time and from unit to unit; and the slowest of the tetanic firings in ordinary movement-contraction may be less rapid in rate than the most rapid of the firings in tonus. Even here therefore there is an over-lap in character between the two, and no hard and fast line between them can be drawn. The electrical reactions in both consist of trains of discrete action-currents. On the centrifugal side of tonus there seems no qualitative distinction between it and ordinary reflex contraction.

On the afferent side the main difference is, at least in the extensor muscles, that the source of the centripetal impulse-stream is preponderantly proprioceptive, including labyrinthine. Yet that character does not of itself constitute any truly qualitative differences between tonus and other reflexes, because proprioceptive reflexes (autogenic excitation and autogenic inhibition) comingle freely, to judge by the extensor muscles, with reflexes of cutaneous and other origin.

Among the interesting papers we have listened to today has been one from Dr. F. Bremer of Brussels in which he showed very clearly the differences of effect of certain drugs upon tonus and upon ordinary reflex contraction respectively. Thus, he demonstrated that curare selectively abolishes the tonus of the decerebrate extensor muscle. Here, however, when the dose of curare is made large the ordinary reflex phasic contraction is also abolished. The difference is, it is true, selective, but none the less it is quantitative rather than qualitative. In like manner the metabolism of the phasic contraction is an intenser metabolism than that of tonus, but that the metabolism of the two exhibits a qualitative as distinct from quantitative difference requires, I think, further proof.

The circumstance that we apply this word *tonus* to particular kind of neuromuscular activity must not lead us to think that because we give that activity a separate and specific name, it therefore follows that the activity itself as a physiological process is a separate and specific entity. We must not let our words be our masters. The term *tonus* comes to us from a time when the doctrine of its existence or non-existence was almost an article of faith. Then, later, for many years it stood for a general condition of slight tension rather mysteriously obtaining in all healthy muscles at all times, a somewhat elusive property, how far peripheral or central, and whether reflex or not, was answered differently by different observers. Tonus as applied to plain muscle in viscera and blood vessels, etc., has a much clearer significance than has its application to the striated muscles of the skeletal musculature. In regard to this last the word originally, as with Galen (and even in the renaissance with Fabricius), denoted active posture. In recent years it has regained something of that original meaning. Certainly the trend of experimental evidence is to show postural tonus to be simply part and parcel of ordinary motility: a manifestation of that ordinary rhythmic neuro-muscular activity by which are executed all our reflex and other acts involving the skeletal musculature. The tonic, i. e., reflex postural form of that activity, because mild and static, involves relatively little expensive metabolism, and is little liable to fatigue.

At the conclusion of our meeting let me offer, on behalf of all of us here, our best thanks both to those who have given the contributions we have listened to so profitably today, and to those who organized the arrangements. For my own part I beg to tender my thanks to our president, Dr. Sachs, and to those with him who accorded me the privilege of presiding on this noteworthy and international occasion.

SUMMARY

Confusion of thought has occurred through the diverse use of the term "tonus." However carefully defined, it now carries with it an incubus of vague connotation which seems to cloud the issue. Its place as a term applied to striated muscle can be more accurately taken over by such specific terms as "standing reflex," "postural reflex" and "righting reflex." The state of a striated muscle at any one moment can be described by such adjectives as "slack" or "taut." Better still, the amount of tension can be measured and stated in quantitative terms.

We make a plea that the term "tone" be either discarded or returned to its former home in smooth muscle and kept there.

"Das Stehen" (Standing: Static Reactions, Equilibrium and Muscle Tonus, with Special Consideration of Their Retention in Animals Without a Cerebellum). Von G. G. J. Rademaker. Price, 69.60 marks. Pp. 476. Berlin: Julius Springer, 1931.

In accepting the responsibility for this review the difficulty of the task was not fully appreciated. At first it appeared that to indicate the nature of the research in a few pages would be sufficient. But the enormous amount of material presented, the numerous and important tests described, the changing symptoms in the same animal following the different operations were all so significant that a brief summary was clearly impossible.

An attempt has therefore been made to present the salient facts of each chapter. The German technical terms for the different reactions which have been retained for convenience and brevity will be found fully described. If errors exist, the reviewer pleads the difficulty of the text.

The monograph is of extraordinary interest, and should be familiar to all who are concerned with these problems.

In his opening comments Rademaker points out that: it is the tone in the muscle that makes standing possible; this tone is regulated by the central nervous system; the connection of the muscles with the cord is not in itself sufficient, for if the cord is separated from the brain the ability to stand is lost, and in lesions of the midbrain and cerebellum this power is more or less destroyed. The object of the research was to find an answer to the following questions: How is standing achieved, and what reactions take part in the normal standing reflex? What part of the central nervous system must be present in order that these reactions may arise? What happens when one or more of these reactions are destroyed? To answer these questions, the following operations were performed. In fifteen animals the entire cerebellum was removed; in five, half of the cerebellum; in three, the whole cerebellum and half of the cerebrum; in two, the cerebellum and the cerebrum; in the five, the entire cerebrum; in one, the cerebellum and both labyrinths, and in one, both labyrinths and half of the cerebrum.

In a general review of the question of standing and the static reactions, attention is drawn to the observations of Duchenne in 1867, who first pointed out that to maintain the different positions of standing a continual activity of the flexor and extensor muscles was necessary. Sherrington showed the influence of the muscle reflexes. He also reported that the rigidity which developed after section of the mesen-

cephalon disappeared when the posterior roots to the feet were cut. Magendie, Longet, Shiff, Vulpian, Christiani, Munk and Goltz demonstrated that animals without a cerebrum could stand, but that the reaction was reflex in character. Luciani observed that animals without a cerebellum showed astasia. Edinger held that the cerebellum was the organ that controlled statotonus. Von Bechterew stated that the cerebellum is the center for static coordination, that the essential preliminary requirement of these reflex muscular activities is that they give rise to a sensation that makes possible an exact determining of the position of the body and the head in relation to the vertical plane, so that at any given moment the effects of a disturbed center of gravity could be overcome. Against these interesting theories Rademaker points to the fact that after extirpation of the cerebellum, both the labyrinth reactions and the static reactions are still present.

The effect of cord injuries on the standing reflexes is carefully considered, as well as the manner in which these reflexes are influenced by the division of the posterior roots. An interesting case of Sherrington's is reported which indicates that proprioceptive irritation may arise in the muscles themselves. The question of whether the tendon reflexes are spinal or have their centers in the midbrain is discussed.

Bastian held the opinion that flaccid paraplegia with anesthesia and absence of all reflexes indicated absolutely that the cord had been completely divided. Gradually, however, cases have appeared to disprove this. Kausch reported the case of a patient with the spinal cord completely divided, in whom a distinct patellar reflex persisted. Head, Riddock and Lhermitte have observed in their examinations of men wounded in the war, with total transverse section of the cord, that muscle tone could appear, as well as spinal and skin reflexes, the achilles, periosteal, and also homolateral flexion and crossed extension. Riddock and Lhermitte emphasized that there is an absolute agreement between the observations in man and the results obtained in experimental animals.

THE CONDITION OF STANDING IN DECEREBRATE ANIMALS

It has been shown by Sherrington that a transverse section through the mesencephalon produces an extensor rigidity; that the rigid legs have a static tonus and that they can, through the standing reflexes, support the weight of the body; that this rigidity is so well marked that the animal stands on its toes, with head retracted, back arched and tail extended. On the other hand, Magnus has demonstrated that the rigidity may be less severe, the elbows and wrist joints showing some flexion, the head not retracted and the tail drooping. In some cases the tonic labyrinthine reflexes exert so strong an influence that when the animal is placed on its back there is a well developed rigidity in the legs. In others, when the head and neck are stretched backward the tonic neck

reflex is so great that the hindlegs show a flexor tonus. These animals can stand only with the forelegs.

THE "STEHBEREITSCHAFT"

Normal standing is made possible through the ability of the animal to place the extremities in the correct position to maintain equilibrium, then through a sufficient *Stutztonus* the weight of the body is supported. To demonstrate this capacity to stand, a normal animal which has been blindfolded is held over a table with the head down, and is then lowered till the muzzle touches. As soon as the animal feels the surface, the forelegs are placed on it, and the legs are then extended, raising the shoulders. The same reaction occurs when the backs of the feet touch the edge of the table. And when the animal is held head up and the body is moved about so that the tail or hindlegs touch the surface, the hindfeet are immediately placed on it and the legs are extended.

The correction of abnormal position of the paws is shown to be influenced by exteroceptive stimuli and the stroking reflex of Munk. Visual impressions alone will give rise to the reaction.

In decerebrate, spinal and thalamic animals, as well as in those without a cerebrum, the capacity to stand is lost. After the removal of the cerebellum, it disappears in a few days. In puppies it is not present for from three to six weeks. That the cerebrum is largely responsible for the reaction in the fore feet is indicated by the fact that after complete extirpation it is absent. After one half of the cerebrum is removed, the reaction is present only in the fore feet of the same side. If in this animal the cerebellum is also removed, the character of the disturbance is not altered. Animals with half a cerebellum or with no cerebellum can place the feet in the proper position for standing through the influence of the visual impressions. From these and other reactions the capacity to stand is considered to be a reflex of the cerebrum.

THE "STÜTZREAKTIONEN"

For normal standing, in addition to the correct position of the limbs, a sufficient supporting tone is necessary. This tone is released through the pressure of the underlying surface on the soles of the feet. When a normal dog or one without a cerebellum is held in the back position, the limbs are flexed. If passive movements are made, one feels some resistance to extension, but hardly any against flexion; a distinct extensor tone is absent. The position of the joints and the tension of the muscles are incapable of supporting any weight. On holding the animal in the air, in the ventral position, the feet are either drawn up against the body or hang partly extended. Passive movements show

some resistance to flexion, though not sufficient to bear the weight of the body. But as soon as the animal is placed on a supporting surface, the limbs at once become firm, owing to the development of a strong extensor tone. The investigation of these phenomena shows that three factors are concerned in the release and maintenance of this supporting reaction: (1) contact with the soles, i. e., the magnet or exteroceptive supporting reaction, (2) the position of the terminal joints and (3) the pressure on the soles.

The Magnetreaktion of the Hindfeet.—Extroceptive impulses originating through contact with the soles of the hindfeet produce extension with fixation of the limbs. This is most clearly observed in dogs without a cerebellum. The extension holds as long as the pressure lasts, whether the eyes are open or closed, and is present in the back and ventral positions as well as when hanging with the head up. If a dog is held in the ventral position by the head and tail, the back is concavely flexed. As soon as the soles of the hindfeet are touched, the hindlegs are extended, and the tone in the back increases. Dogs without a cerebellum show marked reactions even when the back is weighted. These and other tests indicate that by touching the soles of the feet, exteroceptive impulses are released, giving rise to a strengthening of all the muscles in the leg under examination, which are stretched and fixed in extension. There is a strengthening in the pelvis, breast, neck and spinal muscles, a lessening in the extensor tone of the opposite hindleg, as well as changes in the tension of the muscles of the forefeet.

The Magnetreaktion of the Forefeet.—Contrary to the hindfeet, the forefeet of an intact dog, or one without a cerebellum, do not show any reaction in the dorsal position. This difference depends on the wrist joint, which shows a maximal flexion. If the joint is passively extended to 90 or 100 degrees and the sole of the foot is touched, the reaction will appear promptly. When held in the ventral position, the legs are more or less extended. On touching the sole of one foot, it is fully extended and becomes rigid. The appearance of the *Magnetreaktion* depends on the position of the pelvis to the spinal column, and of neck and trunk, the position of the pelvis to the spinal column, and of the feet to the body. The reaction is permanently lost after the complete removal of the cerebrum in decerebrated animals, after extirpation of both labyrinths and after section of the posterior roots connected with the foot under examination. It is temporarily absent following the removal of the cerebellum. It has been observed on both sides when only half of the cerebrum is present.

Influence of the Position of the Terminal Joints on the "Stütztonus."—The position of the terminal joints of the feet are as important as the touching of the soles for the release of the supporting reaction.

If an intact dog or one without a cerebellum is held in the back position and the wrist joint is passively extended without touching the sole, the elbow joint will also be involved and the leg will assume a position of partial extension. In explanation of this close relationship of the joints to one another, it is suggested that the stretching of the flexors, through the passive extension of the joint, gives rise to impulses which evoke a contraction not only in the extended muscles but also in the remaining muscles, and so determines the position and fixation of the elbow and shoulder joints.

Pressure on the Sole.—If an intact dog or one without a cerebellum is laid on its back and the toes and wrist joints are brought into the standing position without touching the sole, then the feet will be stretched out and fixed in the extended position. This fixation is increased when pressure is applied to the sole. Pressure like touch gives rise to exteroceptive stimuli, but the intensity is much stronger. The three factors—touching the sole, the position of the terminal joints and pressure against the sole—constitute the positive supporting reactions. They make it possible for the limbs of intact animals and those without a cerebellum to become so rigid that they are able to support not only the trunk but twice the weight of the body.

Complementary Posture Dependence of the Proximal Joints.—The fourth factor which takes part in the origin of the supporting tone is the complementary posture dependence of the proximal joints. Passive extension of these joints induces extension and fixation of the terminal joints, while passive flexion is accompanied by flexion and relaxation. This complementary reaction explains the alteration in the tone of the forelimbs and hindlimbs of a standing animal when the hindpart or forepart of the body is raised or lowered. It is through these changes in the supporting tone that the position of the legs is brought into proper relation with the actual position of the underlying surface. The correction of abnormal positions of the feet is also due to this associated reaction. If a dog without a cerebrum is stood on a table in such a manner that the forefeet rest on the back of the paws, the position will be immediately corrected as soon as the animal begins to walk. For, as the shoulder joints move forward the wrist joints and the fingers are extended so that the feet are correctly placed on the soles.

The supporting tone is absent in new-born dogs, cats and rabbits. After section of the posterior roots to the feet, all reactions belonging to the standing reflexes are lost. Following transection of the cord the *Magnetreaktion* is absent. On testing the standing reflex of the flexed legs there is no extension, and if the legs are extended there is no fixation.

The supporting reaction is present in all four legs after the removal of the whole or the half of the cerebrum. In dogs without a cerebellum the reaction is at first lost, but returns during the first week. On standing the legs are overextended; when the animal runs the legs are raised too high and too stiffly. In pigeons from which the cerebrum and, an hour later, the anterior lobe of the cerebellum have been removed, the legs hang partly flexed when held in the air, but they become extended and rigid as soon as the feet touch the table. Injury of the cerebellar nuclei increases the tone. A dog with half of the cerebrum and both labyrinths extirpated shows the same reactions in the supporting tone as is found in dogs with but half of the cerebrum. The removal of the entire cerebellum and the right half of the cerebrum produces the same results as when only the right half of the cerebrum has been extirpated.

There is an interesting review of the literature dealing with these reactions in man. Though the question has not been systematically investigated, a number of pertinent observations have been made which indicate that the positive and negative supporting reactions are present. Finally, the question of how the central mechanism of these proprioceptive supporting reactions is to be explained is carefully considered.

THE STRENGTH OF THE SUPPORTING TONE AND ITS ADAPTABILITY TO THE LOAD

If a sand bag is laid slowly on the back of a standing dog, the legs do not bend, but if it is dropped suddenly the legs are first flexed, then extended, showing that the supporting tone was not at first sufficient. This adaptability is accomplished through the increased pressure of the animal against the supporting surface, which intensifies the exteroceptive impulses arising in the soles.

After a careful examination of the strength of the supporting tone in intact animals and those without a cerebellum, in animals with one half of the cerebellum removed, with the complete cerebrum extirpated, in thalamic animals without a cerebellum, in animals without a cerebellum and with only half of the cerebrum present, in decerebrate animals and those without labyrinths, the following conclusions are arrived at: The tone varies greatly under different circumstances. For example, intact dogs can bear a load equal to the body weight; dogs without a cerebellum can carry a load greater than the body weight; in dogs with half a cerebellum, the tone in the homolateral limbs is at first weakened, later normal; with the cerebrum removed, the supporting tone is reduced; with both the cerebrum and the cerebellum removed, the supporting tone is weaker than when only the cerebrum was extirpated; with half of the cerebrum removed, the tone in the opposite limbs is lessened; with

half of the cerebrum and the entire cerebellum removed, the tone in the limbs contralateral to the extirpated half of the cerebrum is strongly and permanently diminished. Decerebrate animals in the standing position usually show a distinct reduction in tone on pressure against the soles. Extirpation of both labyrinths has no effect on the supporting tone. In intact dogs the supporting tone is less in the back position than when standing. In thalamic animals and those without a cerebellum the supporting tone is the same as in intact animals. Decerebrate animals in the back position show a stronger supporting tone than when standing. In human beings with disease of the central nervous system no definite results have been obtained.

Changes in the Supporting Tone on Raising and Lowering the Head.—The adaptation of the supporting tone to static conditions is dependent on the coordination of numerous reflexes having their origin in different parts of the body.

Raising and lowering of the head in intact animals produces distinct changes in the supporting tone and position of the limbs. In the standing position, with the head well back, the tone in the hindlimbs is diminished. With the head flexed ventrally, the tone is increased. In the back position the changes in the tone are inconstant. Dogs with half a cerebellum removed, in the standing position, show changes in the supporting tone equally strong on both sides, but in the back position, on moving the head ventrally, the increase in the supporting tone is generally stronger in the homolateral hindfoot. With the removal of the entire cerebellum, the alterations in the supporting tone and the position changes in the limbs appear a long time after the operation in both the standing and the back position. In the standing position, with the head ventrally flexed, the increase in the supporting tone in the hindlegs is less than in intact animals. In the back position the tone is almost completely lost.

The importance of the changes in the supporting tone on raising and lowering the head is to enable the animal to adapt itself to its static surroundings. When an animal is stood on a support which is raised at the tail end, the head in sinking will be passively moved forward. Through these position changes of the head in space the labyrinth reflexes are brought into play and the head resumes its original position. Both the labyrinth reflexes and the tonic neck reflexes are responsible for the changes in the supporting tone and the position of the extremities.

The vertebra-prominens reflex observed by Magnus and de Kleijn in decerebrate animals is released either through the ventral displacement of the neck in the lower cervical joints, or through pressure on the spinous processes of the lower cervical and upper dorsal vertebrae. It produces a diminution in the extensor tone of the forelimbs and hind-

limbs. The reaction can be obtained in intact dogs, as well as in those without a cerebellum or cerebrum.

Changes in the Supporting Tone on Turning or Rotating the Head.—When the head of a decerebrated animal is passively turned, there is a diminution in the rigidity of the extremities on the side to which the vault of the cranium is directed, and an increase in the extensor tone of the limbs on the side toward which the jaw points. These are due to tonic neck and labyrinth reflexes.

In a number of interesting experiments the following points are demonstrated: If an animal with half or the entire cerebellum removed or with half or the whole cerebrum extirpated is stood on one foot, the turning of the head produces no definite changes in the supporting tone. On the contrary, distinct changes in the supporting tone appear when the head is turned in animals without a cerebellum, when they again begin to stand. In the cerebellar animals the tonal changes occur in the limbs on the side of the operation; in the cerebral animals the changes appear in the contralateral extremities. In the back position, dogs with half or the entire cerebellum removed show, sometime after the operation, on turning the head, distinct changes in the strength of the supporting tone in the hindfeet. Intact animals or those with half or the whole cerebrum removed show no changes.

These alterations in the supporting tone produced by turning the head are of importance in adapting the animal to static conditions. If one places an intact animal or one without a cerebellum, with the eyes closed, on a horizontal surface and then raises the left side, the right side will sink so that the animal passively in the long axis is turned to the right. The head is then rotated to the left; the left limbs are flexed and the right extended. This adaptability of the position of the feet to a surface which is raised sideways does not definitely mean that the changed position of the head is responsible. The reaction probably originates as a labyrinth reflex. These reflexes in their various forms, and combined with the "lift" and *Sprungbereitschaft* reactions are carefully considered and well illustrated.

It has been shown in decerebrate animals that moving the head effects tonal changes in the extremities. Turning the head to the right, i. e., bringing the right ear toward the right shoulder, the right limbs show an increase in the extensor tone, the left a diminution. Ventral and horizontal positions produce other changes. Contrary to these reactions, intact animals and those without a cerebrum, in the back position, do not show any distinct changes on turning the head; the limbs remained flexed. But when standing on all four feet, the turning of the head has a distinct influence. With the head turned to the right, the center of gravity is shifted to the right and there is a distinct increase in the tone of the right foreleg and a diminution in the left.

Influence of the Position of the Spinal Column and Pelvis on the Supporting Tone.—Another factor that influences the position of the spinal column is the relation of the limbs to the trunk. If an intact animal or one without a cerebrum is placed in a standing position and the hindlegs are moved backward, the back will be observed to sink. On moving the feet forward, the opposite condition appears. In animals without a cerebellum the dorsal convexity is increased, while in intact animals the hollow back is straightened or convexed. These various reactions have been carefully observed; the anatomy of the muscles concerned is shown, and the tonal changes are reported.

Influence of the Position of the Back on the Supporting Tone.—If a dog is held firmly by head and shoulders with the hindfeet resting on one hand, when the feet are lowered the convexity of the back increases, the legs are stretched out and show a strong supporting tone. On moving the feet upward the back becomes concave, the limbs are flexed and the tone is reduced. Dogs without a cerebrum show the same reactions. In those without a cerebellum the supporting tone appears later. The curvature of the back also affects the adaptability of the limbs to the underlying support. This is demonstrated by placing the forefeet and hindfeet on different surfaces and changing their position.

Influence of the Position of the Pelvis on the Supporting Tone of the Hindfeet.—When the pelvis is moved ventrally or dorsally on the lower joints of the lumbar vertebrae, changes in the supporting tone of the hindlimbs appear. If an intact dog is placed on a board in the chest position so that the pelvis and hindlegs hang over the end, on moving the pelvis dorsally a stronger supporting tone will be observed in the statically tested leg than is found when the pelvis is moved ventrally. Dogs without a cerebellum show the same reaction in the back position. Lay a dog on a table in the dorsal position, the pelvis resting on a board, the forepart of the body firmly fixed and the muzzle at an angle of plus or minus 45 degrees. Then move the board upward till the spine shows a convexity between the thoracic and lumbar regions. If pressure is now applied to the sole of the hindfoot, the limb will be immediately extended and the tone increased.

In man the influence of the curvature of the spine and the position of the pelvis on the supporting tone in the limbs has not been fully investigated. An interesting discussion of certain cases reported in the literature is included in which the abnormal synergic reactions are carefully compared with similar disturbances in animals.

Shoulder Reactions.—The manner in which the position of one limb affects the supporting tone in the opposite limb is demonstrated by passively lifting the right foot of a standing dog and gently pushing the trunk to the right. A strong extension and abduction is then felt in the

elevated leg. This reaction does not depend either on the optic impulses, the labyrinths or the neck reflexes, for it is also present when the head is fixed and the eyes bandaged. It is due to changes in the position of the opposite leg.

The shoulder reaction is lost after section of the posterior roots. Extirpation of the cerebellum inhibits it for a week. With half of the cerebellum removed, it is at first lost and later returns. In dogs without a cerebrum, the reaction returns on the second day. In total extirpation of the cerebrum and cerebellum there is no reaction. With the cerebellum and right half of the cerebrum removed, the left limbs show an exaggerated shoulder reaction. In decerebrate animals and after transection of the cord, the reactions on both sides are lost. In man the shoulder reaction is absent until standing and walking appear. A patient with a gunshot wound in the right cerebellar hemisphere, on passively moving the body to one side or the other, showed that he could raise the right leg from the floor but not the left.

Importance of the Shoulder Reactions in the Preservation of Equilibrium.—If a running dog is suddenly pushed to the left while the left forefoot is raised, the passive abduction of the right leg releases a shoulder reaction in the left leg. The effect of this is to produce a strong extension and abduction of the left foot which prevents the animal from falling. If the animal is stood on a board, which during the lifting of the left foot is moved to the left, then the center of gravity will be drawn to the left, and the right leg brought into a position of abduction. This again induces an active extension and abduction of the raised left foot, which then assumes a correct position to the underlying surface.

Reactions on Strong Abduction of the Contralateral Limb.—If a dog is held in such a position that the right hindleg rests firmly on a surface, fixed by the hand so that it cannot move, and is then slowly abducted, the left hindfoot will be raised, extended and abducted to be placed beside the right foot. When an intact animal standing on all four feet is drawn to the right, the right feet will be placed more to the right and the left feet will be abducted and placed beside them. Animals with the left half of the cerebrum removed, or with the whole of the cerebrum extirpated, when drawn to the left side show the same reactions as a normal animal. These and the reactions in animals without a cerebellum are carefully observed and described.

Changes in the Supporting Tone of One Foot on Moving the Contralateral Foot Forward and Backward.—If a dog is placed on a support with one forefoot exactly in the middle position, the other on being passively raised is found easy to flex and no attempt is made to extend it when the hand supporting the sole is moved. But on shifting the body forward a strong extensor movement develops and the limb is diffi-

cult to flex. A similar reaction occurs when the body is moved backward. The important factor is the change in the position of the supporting leg to the body. These reactions are present in intact animals as well as those in which the labyrinths have been removed, or the cerebrum or cerebellum extirpated. They are absent in decerebrate animals.

Influence of the Position of the Forefeet on the Supporting Tone of the Hindfeet.—In a number of well illustrated tests the movements of one or both forefeet forward showed an increase in the supporting tone in both hindlegs. The tone in the hindlegs is diminished when the forefeet are moved backward. When the hindfeet are moved forward the supporting tone in the forelegs is diminished. On moving them backward the tone is increased. Slight adduction of one foot decreases the supporting tone in the opposite foot and increases the tone in the moved foot. With strong adduction the reaction is reversed. Slight abduction of one foot increases the tone in the opposite limb while strong abduction decreases it.

Effect of the Position of the Foot on the Supporting Tone of the Leg.—A. The *Stemmbein* Reaction: If a dog is stood on one foot the strength of the supporting tone depends on its position. In strong abduction it is weak, the elbow joint giving to slight pressure on the shoulder. When the leg is brought into the middle position the tone is increased. Forward and backward positions show a diminished tone. This reaction plays an important rôle in the adaptation of the position of the legs to the supporting surface. It is present in intact animals, as well as those without cerebellum or cerebrum. It is absent in decerebrate and spinal animals.

B. The *Hinkebein* Reaction: When a leg is passively moved more and more from its middle position, the supporting tone becomes less and less, and the leg is shifted into a better position to support the strain. The reaction is present in intact dogs with eyes bandaged, and in dogs without a cerebrum. With half of the cerebrum removed, the reaction is present in the contralateral leg. With half or the entire cerebellum extirpated, the reaction is at first lost but later returns. It is also demonstrable in animals without a cerebellum and with only half of the cerebrum present, as well as in animals after extirpation of the labyrinths. In decerebrate and spinal animals and in those in which the posterior roots have been cut, it is lost.

In the adaptation of the relation of the legs to the changed position of the underlying surface, the following factors take part: labyrinth rotating reactions; labyrinth progressive reactions; the position reflexes; the influence of the position of the distal joints on the proximal; the

influence of the curvature of the back on the supporting tone; the shoulder reactions; the influence of the position changes in one foot on the supporting tone in the opposite foot, and the *Stemmbein* and *Hinkebein* reactions.

In man with multiple sclerosis the reactions are absent.

C. The Proprioceptive Correction Movements: Attention has already been called to the fact that dogs without a cerebrum, in spite of the absence of the *Stehbereitschaft* reactions, optic and body impulses, do not show any abnormal position of the feet either standing or running. Contrary to those animals in which the posterior roots from the feet have been cut, and spinal animals which allow the dorsal side of the feet to drag on the floor, the animal without a cerebrum places the soles of the feet correctly on the underlying support.

These reactions are present in intact animals as well as in those without cerebrum, cerebellum or labyrinths. They are absent in decerebrate and spinal animals and those in which the posterior roots have been cut. In man no definite conclusions have been arrived at.

THE MANNER IN WHICH STIMULI FROM THE SURFACE OF THE BODY, THE ACOUSTIC AND OPTIC APPARATUS INFLUENCE THE SUPPORTING TONE

The importance of stimuli arising in one part of the body surface, viz., the soles of the feet, has already been spoken of. Further, it has been mentioned that intact dogs and those without a cerebrum, when held in the air in the ventral position, show a strong extensor tone in the limbs when pressure is made against the soles of the feet, while with the back resting on a supporting surface the extensor tone is weak, and in the hindlegs is sometimes quite lost. These observations deserve special attention because, according to Magnus and de Kleijn, they are found in dogs when placed in the maximum position for the tonic labyrinth reflexes.

In consequence of these reflexes decerebrate dogs in the back position with the muzzle above the horizontal show extensor rigidity in all four legs, which is distinctly stronger than in the ventral position or on standing, if the muzzle is held 45 degrees below the horizontal. Dogs without a cerebellum also pass through a stage of prolonged diminution in the supporting tone when in the back position. These reactions may be explained by the fact that in intact animals and those without a cerebrum in the back position the stimuli arising from pressure on the surface of the back induce a diminution in the supporting tone. If the animal is raised by the hands under the neck and pelvis, the supporting tone is found to be immediately increased as soon as the pressure against the back is removed.

Animals without a cerebrum in the standing position show so strong a reduction in the supporting tone when a fold of the skin of the back is gripped that the limbs collapse under the weight of the trunk.

In a normal man lying on his back the legs can be easily flexed by pressure against the soles of the feet, but on standing it is hardly possible to bend the legs by pressure on the shoulders. This makes it possible for dock laborers to carry loads of 100 Kg. or more.

Acoustic Stimuli.—Intact dogs and those without a cerebrum lying quietly in the side position react to certain noises by pointing the ears, raising the head and stretching the paws. Also, if a table is struck sharply by the hand a standing animal will be observed to crouch. These changes are the result of subcortical reactions.

Optic Stimuli.—These can also release conditional changes in the supporting tone in dogs with intact cerebrum. This was particularly well shown in an animal without a cerebellum when placed on a floor covered with *Holzgranit*. The dog would not stand up but crept about. When straw was thrown in a corner he crawled over to it and when a few paces away stood up straight, took a few quick steps and fell on it. Later he stood up on the straw.

GENERAL CONSIDERATION OF THE CENTER OF GRAVITY REACTIONS AND THEIR RETENTION IN ANIMALS WITHOUT A CEREBELLUM

This chapter includes an interesting discussion on the question, and the views of some of the leading authorities for and against the opinion that the cerebellum is the main organ of equilibrium are carefully considered.

Rademaker points to the difficulty of reaching any satisfactory conclusion until it has been definitely settled just what an organ of equilibrium really means. According to him, an equilibrium organ is a center through the intervention of which one or more equilibrium reactions are brought into play. Such a reaction is a complex of movements by which equilibrium is maintained, or if lost is again set up, i. e., through the influence of which the center of gravity of the body is maintained within the supporting surface, or will be brought back to this.

Retention of the Position Reflexes in Animals Without a Cerebellum.—Labyrinth Reflexes: These are necessary for the maintenance and readjustment of the head in a normal position. They are present without exception in all animals without a cerebellum, as well as in animals with half of the cerebellum removed.

Neck Position Reflexes: By turning the head, stimuli are released in the deeper parts of the neck which affect the position of the neck and chest. In intact animals and those without a cerebellum, the return of the head to the normal position is followed by the trunk and pelvis. In

falling sideways, the labyrinth reflexes bring the head back to the normal position, and after that through the neck reflexes the equilibrium of the body is resumed. The neck reflexes are present in all animals without a cerebellum.

The influence of the body-position reflexes on the head can only be determined in animals without labyrinths and with the eyes closed. In the cat, Peggy, both labyrinths were removed and the body-position reflexes were lost. Three weeks later, the cerebellum was extirpated and two days after the operation the reflexes reappeared. This cat also showed a more marked ataxia than animals without a cerebellum with both labyrinths intact.

If the cerebellum were the central apparatus of the labyrinth reflexes, then extirpation of the labyrinths in animals without a cerebellum would not produce any symptoms. But Magnus has shown that unilateral labyrinthectomy in an animal without a cerebellum produces the same symptoms as in intact animals. Rademaker claims that these observations are against the idea that the cerebellum is the central apparatus of the labyrinth reflexes.

Raising and Supporting Reactions of the Forefeet: If a normal cat is walking along the edge of a roof and the hindfeet fall off it will hold tight with the forepaws, raise itself until the center of gravity is anterior to the shoulders, and then place the hindfeet beside the forefeet. Cats without a cerebellum, with or without the eyes bandaged, can recover their center of gravity when hanging on the edge of a table. Cats without a cerebrum can also draw the body up, but owing to the failure of the *Stehbereitschaft* reaction the hindfeet are not set on the underlying surface. This supporting reaction is developed through the activity of the flexors following passive extension of elbow and shoulder joints; also through the ventral flexion of the head and neck as a result of the labyrinth reflexes induced by the backward passive movement of the animal.

Retention and the Restoration of the Center of Gravity in Animals Without a Cerebellum Through the *Schunkel, Stemmbein* and *Hinkebein* Reactions: The facts of these investigations show that in cats and dogs without a cerebellum no definite lasting loss of a single reaction of equilibrium position reflex, or labyrinth reflex can be pointed to. From this one can conclude that thus far no ground exists for the assumption that the cerebellum is to be considered as the central apparatus for the regulation of equilibrium and the labyrinth reflexes, and that these reflexes must therefore have convenient centers in the neighborhood of the cerebellum to which the afferent and efferent tracts run.

Thomas has suggested, and many agree with him, that the restoration of the capacity to maintain equilibrium in an animal without a cerebellum

is due to the compensation of the cerebrum. Opposing this view, Rademaker cites the thalamic animal, Robbie, in which the cerebellum was also removed, which showed five weeks after the extirpation a return of the labyrinth reflexes from the side position of the *Hinkebein* reaction in the hindfeet, to demonstrate that equilibrium reactions can appear without the compensatory influence of the cerebrum.

There is also a careful investigation of the manner in which equilibrium is preserved in animals without a cerebellum when on a turntable, as well as of the reactions of the spinal column and pelvis in maintaining the center of gravity.

GENERAL COMMENT ON MUSCLE TONE, ESPECIALLY IN RELATION TO ANIMALS WITHOUT A CEREBELLUM

Leven and Olliver, from their observations on seventy-six cases of cerebellar disease, claimed that the disturbances in movement depended on muscle weakness. Luys came to the same conclusion. Weir Mitchell considered the cerebellum as a source of energy for the spinal centers influencing voluntary and involuntary movements. According to Luciani, the cerebellum does not possess any individual field of action that is not influenced through the centers of the cerebrospinal system. He considered that its function is a strengthening one, and its disturbance is indicated by asthenia, astasia and atonia. He defines tone as the active tension of a muscle at rest, and strength as the energy developed in a muscle in its different voluntary, automatic and reflex activities.

In the present discussion *muscle tone* is understood to mean the tension with which the muscle resists a passive change of position, and *muscle strength* the maximal power with which a muscle can perform a movement, which is determined by measuring the power necessary to prevent the movement. This resistance comes normally into action through the stretching of the muscle substance, through reflex stretching, and the stretching due to the influence of the cerebrum. These stretching reflexes and their influence on muscle tone receive particular attention, each of the six orders being carefully considered.

Extirpation of the cerebellum, both in otherwise intact animals and those without a cerebrum, results in a rigidity which has the characteristics of decerebrate rigidity. This rigidity is explained by some as being due to the falling out of the red nucleus, by others as due to shock, diaschisis or inhibition. The question is not settled.

Animals without a cerebellum show distinct and important changes due to disturbances in muscle tone through interference with exteroceptive and proprioceptive stimuli. With half the cerebellum removed there is often as much rigidity as after total extirpation. This is opposed to the observations of Luciani and others who maintained that with half the cerebellum removed there is hypotonus of the homolateral muscles.

INVESTIGATIONS OF STANDING, THE REGULATION OF MUSCLE TONE AND THE MOTILITY OF ANIMALS WITHOUT A CEREBRUM

In dogs without a cerebrum, all of the position reflexes, labyrinth, neck and body, are present. The optic alone is absent. These animals can stand and walk in apparently a normal manner and with seemingly a normal distribution of muscle tone. But investigation of the different reactions reveals the following disturbances: The *Stehbereitschaft* reaction fails, owing to the loss of impulses from vision and the body surface. There is also a distinct disturbance in correcting the abnormal position of the feet, indicating that this reaction passes through the cerebrum. The *Magnetreaktion* is lost. The proprioceptive *Stützreaktion* has disappeared. In the *Hinkebein* reaction the leg is raised too high and set down too broadly, the step is abnormally wide and less brisk than in animals without a cerebellum.

The manner in which the distribution of muscle tone is influenced by the position of the head, through the tonic neck and labyrinth reflexes has only been in part determined. In the standing animal, raising and lowering the head, in intact dogs as well as those without a cerebrum, show a definite increase and decrease in the supporting tone. While in the back position the four legs remain more or less strongly flexed in all positions of the head, even when the soles of the feet are pressed against.

Animals without a cerebrum differ from normal animals in that the following reactions are destroyed: (1) reactions due to stimuli arising from the body surface—the preparedness to stand, and the correction of abnormal position of the feet are lost; the *Magnetreaktion* is weakened or has disappeared; gripping the skin of the back causes flexion of the legs; stroking the back against the hair causes extension of the legs; (2) reactions to proprioceptive stimuli released through the muscles—the supporting tone in the hindlegs is weak; the *Hinkebein* reaction is delayed, as are also the correction movements, the *Stemmbein* reactions, and the reactions due to stimuli arising from the labyrinths.

A decerebrate animal differs from an animal without a cerebrum as follows: gradual diminution of the extensor tone in the standing position, while in animals without a cerebrum the legs can bear the weight of the body through the incompletely developed *Stütz* reaction; failure of the labyrinth and body reflexes; loss of the *Schunkel, Hinkebein, Stemmbein, Aufzich* and *Aufstemmbein* reactions; failure of the inhibiting influences of the back position on the muscles of the extremities. In decerebrate animals in the back position the extremities are particularly stiff, while in animals without a cerebrum practically no supporting tone is present.

THE DISTURBANCES OBSERVED IN THE FUNCTION OF STANDING AND POSITION AFTER ONE HALF OF THE CEREBELLUM HAS BEEN REMOVED

The symptoms immediately following the operation differ in almost every experiment, but in no case has an animal been able to right itself or stand unsupported. Later in the stage of permanent disturbances, the symptoms are practically always the same; the animals can right themselves, stand freely and run about. Some show rolling movements to the side of the operation, possibly due to injury of the vestibular apparatus.

In the first stage one usually observes on the homolateral side that the distribution of tone is abnormal; that the *Stehbereitschaft* and *Magnet* reactions fail; that the *Stütz* reaction is disturbed; and that the *Hinkebein, Stemmbein* and *Schunkel* reactions, as well as the *Körperstell* reflexes are lost. Inconstant symptoms are the turning of the head with the vault of the cranium toward the side of extirpation and disturbances in the labyrinth position reflexes, also in the body position reflexes when lying on the intact side; on the contralateral side the *Magnet, Stütz, Hinkebein, Stemmbein* and *Schunkel* reactions are abnormal.

In the stage of permanent disturbances the animal is again able to stand and run. It can carry a sand bag almost equal to its body weight. Moving toward the side of extirpation, the hindfeet make running steps, toward the intact side, the hindfeet show the *Hinkebein* reaction. On drawing the animal toward the intact side, the hindfeet on this side are placed normally. In walking, the homolateral legs are flexed too strongly. The *Stehbereitschaft, Magnet* and *Stütz* reactions reappear.

The disturbances frequently found in the contralateral limbs are possibly due to injury of the remaining half of the cerebellum at the time of operation. It is also possible that the function of the remaining half of the cerebellum may be interfered with through the loss of stimuli which normally arise in the removed half.

DISTURBANCES AND SO-CALLED CEREBELLAR ATAXIA IN ANIMALS WITHOUT A CEREBELLUM

In complete extirpation of the cerebellum, some animals show rigidity, and others, a well marked flaccidity. When rigidity is present the *Stütz* reactions, the distribution of muscle tone and the suspension of the *Stell* functions are similar to those found in decerebration. And in spite of the fact that these animals can see and react to optical impulses with eye movements and wagging of the tail, they nevertheless lie permanently in the side position, cannot raise the head, and the *Stehbereitschaft* reaction is destroyed. Stood on its feet, such an animal can carry the weight of its body. Passive movements of the head show the pres-

ence of neck and labyrinth reflexes, though these may be observed only after several days when the rigidity has somewhat lessened.

The flaccid animal, on the other hand, lies with the limbs flexed. The neck muscles are also weak, and the head cannot be held upright. Nevertheless, even on the day of operation the head may be turned into a normal position, though the jaw will be resting on the floor. The raising of the head from the side position when the animal is lifted shows the presence of the labyrinth reflexes. The activity of the neck reflex is also indicated by the forepart of the body being brought into the breast position when the head is turned. The fact that the hindpart of the body remains on its side shows that the body righting reflexes arising from the body are absent. The tone of the limbs is only slightly increased by pressure against the soles, and when the animal is brought into a standing position the limbs are unable to support the weight of the body.

In both the rigid and the flaccid animals the body reflexes arising from the body, the *Magnet, Stemmbein, Hinkebein, Stehbereitschaft* and *Schunkel* reactions are lost. The first of these to reappear are the *Magnet* and *Stehbereitschaft* reactions. In the flaccid animal these may be observed during the first week, but will not be present in the rigid animal till the second to fourth week. As the reactions return the animal begins to creep about with its forefeet, the hindfeet being still in the side position as the body position reflexes are still absent. On trying to raise itself it falls, owing to the absence of the *Stemmbein* and *Hinkebein* reactions. With the return of the *Körperstell* reflexes, the hindpart of the body is brought into the ventral position, but as these reflexes are still weak and the *Stemmbein* reactions have not returned, the neck position reflexes are unopposed and each strong turning or rotation of the head results in a fall. It is considered that the inhibiting action of the cerebrum is responsible for this, for if a limping animal is taken hold of by a fold of the skin and so prevented from falling, it will raise itself, the limbs becoming extended and fixed; as soon as the skin is released the flexion in the limbs reappears. Eventually, as these reactions become stronger, the disturbed center of gravity is corrected and the animal is able to walk straight. In from three to six months, the stage of permanent disturbances is reached and the animal shows the typical appearances which in man are usually considered under the name of cerebellar ataxia.

Contrary to the conditions previously observed, the symptoms in the stage of permanent disturbances in dogs and cats are in general exactly the same. Animals now show a prompt *Stehbereitschaft* reaction to both optic impulses as well as to those arising from the body surface. And the ability to correct abnormal positions of the feet to exteroceptive stimuli is also present. On the other hand, a number of distinct reac-

tions are lost, e. g., the *Magnet, Stütz, Stehbereitschaft* and *Hinkebein* reactions. Disturbances are also to be observed following changes in the position of the head.

Uncontrolled reactions in animals without a cerebellum consist of tremor and simple uncontrolled movements. Tremor is not always present, but as a rule these animals cannot stand quietly, there is a continuous motor unrest. The tremor continues after extirpation of the cerebrum and after transverse section of the midbrain with injury of the red nucleus. Tremor ceases when the paws are touched or pressed against, when the animal lies quietly in the side position and during sleep. In these animals division of the midbrain caudal to the red nucleus will also cause the tremor to disappear. These disturbances may be qualified by the inhibiting influences of the back position, by the delayed appearance of the *Hinkebein* reactions, and by the abnormal muscular activity to different stimuli.

The symptoms observed after the extirpation of the cerebellum have had the result of raising a strong controversy over the question whether the cerebellum should be considered as an organ of coordination. The view that the cerebellum was an organ of coordination was first expressed by Flourens, and recently again by Bechterew, Bolk, Jelgersma, Hulshof Pol, Bárány and Dusser de Barenne. This was strongly opposed by Luciani, Rynberk and others.

Flourens observed that animals without a cerebellum were able to contract their muscles and perform certain complicated movements, though they were unable to stand unsupported nor could they run or spring. He came to the conclusion that the ability to incite or combine muscular contractions centered in the spinal cord, while the power to coordinate movements such as walking, springing, etc., arose exclusively in the cerebellum, and that the cerebellum was therefore an organ of coordination.

Luciani drew attention to the fact that animals without a cerebellum could swim. This he considered a crucial test showing that the coordination was not destroyed, and that therefore the cerebellum was not an organ of coordination. According to his view an organ of coordination is one which, otherwise than through the tonic, asthenic and static effects, regulates the normal course of movements. Such an organ would exercise an influence on all actions, and the observation that a single action could be carried out in a normal manner would prove that coordination had not been suspended.

According to Jelgersma, the cerebellum coordinated only the acquired higher forms of associated movements such as speaking, running, springing, climbing, etc., which come into being through the cerebrum under the influence of the optic, acoustic and skin stimuli, as well as from the

impulses arising from the muscles, joints and labyrinths. In this connection it must be mentioned that dogs without a cerebellum have been heard to bark, growl and whine; and cats to purr, hiss and mew. Nevertheless, this does not mean that in man the cerebellum has no influence over speech.

Munk has mentioned that in animals without a cerebellum there are certain movements that at times are hardly noticeable which under other conditions are definitely abnormal. In the free standing position there are a number of awkward actions, such as scratching without touching the skin, which are almost normally performed if the animal is leaning against a wall or lying down.

Rademaker does not take any position in this controversy because he considers that the physiology of the cerebellum has not been sufficiently advanced to form an opinion. Also because the dispute largely depends on the unsettled question of what is meant by an organ of coordination, and what is the definition of an uncoordinated movement, for animals show disturbances not only in their actions but also standing—incoordinate standing.

A COMPARISON OF THE DISTURBANCES FOUND IN ANIMALS WITHOUT A CEREBELLUM WITH THE SYMPTOMS OBSERVED IN CEREBELLAR DISEASE

Asynergia.—In the first stages after the operation certain associated movements are abnormal. If the head of an animal in the ventral position is rotated to the right, the whole body turns over to the right side. In intact animals and those without a cerebellum in the stage of permanent disturbances, the pelvis is turned to the left. During the first days the trunk obeys the neck position reflexes on the body and the *Stemmbein* reactions. That is, through the loss of some reactions and the unrestricted activity of others, the animal shows a certain degree of asynergia. Later, on rotating the head the same synergic reactions are observed as in the intact animal, i. e., a spinal rotation of the trunk and a typical reaction of the feet which prevent falling.

Adiodokokinesia.—This condition cannot be satisfactorily examined.

Cerebellar Catalepsy.—According to Babinski, if a patient with cerebellar disease is laid on his back and the hip and knee joints are flexed to an angle of 90 degrees, the leg will not show any trembling. On the contrary, in a normal person as soon as the leg becomes tired a coarse tremor will be observed. Though it is not possible to reproduce the same test in animals, nevertheless some conditions have been noticed which appear important in respect to cerebellar catalepsy. If an animal with the cerebellum removed is laid on its back with the muzzle directed upward, the limbs will be held in a stretched-up position. They will not

tire for some time and no trembling will be observed. With half the cerebellum removed, the limbs on the same side as the extirpation will show the same symptoms.

Hypermetria.—When a patient with cerebellar disease attempts to take a glass of water, the hand is too widely opened. In the monkey, Carrie, without a cerebellum, the same reaction has been observed. In other animals hypermetria has been found in the movements of running, and in the *Hinkebein* and *Schunkel* reactions.

Rebound Phenomenon.—This feature, observed in man with cerebellar disease, also has its counterpart in animals without a cerebellum. This may be tested by gripping the tail and pulling backward. As the animal naturally pulls forward, if the grip is suddenly loosened it will go much farther forward before stopping than a normal animal.

Passivity.—According to André Thomas, this is the lowering of resistance to passive movement through hyposthenia of the antagonists. This passivity is observed in the abnormal swinging movements of the arms when the trunk is passively turned to the left and right, in the swinging movement of the hand at the wrist joint and in the pendulum reaction of the patellar reflex. The presence of this reaction in animals without a cerebellum is clearly indicated in the abnormal swinging of the hindlegs when the animal is held in the air and swung to and fro.

Astasia.—Animals without a cerebellum show distinct ungoverned movements which make it impossible to stand still.

Nystagmus.—The spontaneous form is not found.

Past Pointing.—These and similar conditions are difficult to prove, but in the monkey, Carrie, without a cerebellum, a distinct failure to grip was sometimes observed, during the first stage.

Atonia and Asthenia.—These are absent in animals without a cerebellum. Hypotonia is also often missed. Occasionally a well marked hypertonia with rigidity is observed.

THE PHENOMENA FOLLOWING THE COMBINED EXTIRPATION OF THE CEREBELLUM AND CEREBRUM

The animal without a cerebellum and with the right half of the cerebrum removed at the same time showed at the conclusion of the operation an extensor rigidity exactly like an atypical decerebration. Gradually the condition changed. The rigidity disappeared from the right leg, while the left remained stiff even in the back position in the stage of permanent disturbance. Later, an asymmetric distribution of muscle tone in the neck was observed. In the stage of permanent disturbances a typical combination of symptoms was noticed. It has been seen that when the cerebrum or the cerebellum has been extirpated, the

Hinkebein reaction was delayed, and only appeared when the positions were definitely changed. In the present instance, with the cerebellum and right half of the cerebrum removed, the *Hinkebein* reaction in the left leg was more strongly disturbed than in the right. The delay of the reaction was so marked that it was unsuitable to maintain and readjust the center of gravity. As a result, the animal never learned to stand free or to run. The usual position of the animal was with the hindpart of the body in the right side position and the forepart in the ventral position, with the head raised and generally turned to the left.

The most important symptoms are: (1) Hemianopia. (2) Failure of the *Stehbereitschaft* reaction owing to the loss of optic impulses as well as the stimuli arising from the body surface. On touching the lower jaw against the edge of the table, only the right forefoot was placed on the table, while the left remained hanging, with extended elbow and wrist joint. Laid on a latticed table with the legs drawn through the openings, only the right legs were withdrawn and the soles of the feet placed on the framework. (3) Lowering of the strength of the supporting tone in the left leg. Although the left leg showed an increased inclination for the extended position, with a distinct extensor tonus, the supporting tone was nevertheless not so strong as in the right. If the animal was placed so that only the right foreleg rested on a supporting surface, it did not give way under a weight of 5 Kg. placed on the shoulders, while the left leg bent under a weight of 1 Kg. (4) Greater disturbance of the *Hinkebein* reactions and the proprioceptive corrective movements in the left legs than in the right. It is considered that this result is only partially associated with the removal of the cerebellum, and is due principally to the extirpation of the right half of the cerebrum, because a similar difference was observed in an animal with the cerebellum intact and with only one half of the cerebrum removed.

Symptoms Following Removal of the Left Half of the Cerebrum.—The *Stehbereitschaft* reaction is disturbed on the right side. Hemianopia is present. The animal runs in circles to the left. The *Hinkebein* reactions in the right feet are disturbed, and the strength of the supporting tone is reduced in the right limbs.

Symptoms Following Removal of the Remaining, or Right Half of the Cerebrum.—The running in circles to the left disappeared. This was all the more extraordinary because in the standing position the head was always turned to the right. The optic and acoustic reflexes were absent, as well as the *Stehbereitschaft* and the stimuli from the body surface. The animal could walk well and did not show abnormal extension of the limbs. Correction of the limbs to proprioceptive stimuli was present. The supporting tone in the forelimbs was plus, in the hindlimbs minus. The *Hinkebein* reactions were prompt, and the coordination of the feet in walking was normal.

Extirpation of the cerebellum in an animal without a cerebrum, as in intact animals, is followed by decerebrate rigidity. Following the extirpation the animal lies rigidly on its side, the neck drawn backward, the back arched and the tail extended dorsally. Labyrinth and *Korperstell* reflexes are absent, and there is no attempt of the animal to right itself. Pressure against the soles increases the stiffness. If stood on its feet there is well marked extension of the limbs and retraction of the head. The limbs are not flexed by the weight of the body. In the back position the limbs are also stiff. Absent reflexes include the *Schunkel, Stemmbein* and *Hinkebein* reactions, as well as the corrective movements to proprioceptive stimuli. Ear muscle, sneezing, the corneal and eyelid reflexes are present. Meat was swallowed from the third day on. Urination and defecation were spontaneous. Rigidity had mostly disappeared by the end of the week. The strength of the supporting tone was now less than that before the extirpation of the cerebellum. During the second and third weeks, with the further reduction of the rigidity, the labyrinth reflexes returned. In the fourth and fifth weeks the extensor tone was still further reduced and the animal showed positive and negative supporting reactions.

From a comparison of the reactions observed in animals in which both the cerebrum and the cerebellum have been removed with those found in animals with intact cerebellum but with the cerebrum extirpated, one is not able to conclude that the difference depends exclusively on the loss of the cerebellum.

Although in the dog, Robbie, the investigations did not yield the desired results, they have nevertheless given certain definite reactions: 1. The extirpation of the cerebellum, even in dogs without a cerebrum, permits the development of the same rigidity with plasticity that is found after decerebration, and the rigidity in the fully developed state can last a week. 2. The rigidity gradually diminishes and almost disappears. 3. The diminishing rigidity is accompanied by a return to the *Stütz* reaction. Through this the statically tested hindlegs can carry a heavier load than the stiffly extended hindlegs of animals in the rigid stage in the standing position. 4. The *Stütztonus* strength after the removal of the cerebellum is indeed at first diminished, notwithstanding that in animals without a cerebrum the same power is again attained as before the extirpation of the cerebellum. 5. Even in dogs without a cerebrum some of the reflexes, such as the labyrinth position reflexes and the *Hinkebein* reactions, which in the first days after the extirpation of the cerebellum are completely lost, gradually return. Consequently, the reappearance of equilibrium after the removal of the cerebellum does not depend entirely on the compensation of the cerebrum, as has been maintained by some authors.

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News and Comment

NEW YORK PSYCHOANALYTIC INSTITUTE

The New York Psychoanalytic Institute offers the following courses during the year 1932-1933, beginning the end of September, 1932: (1) Psychoanalysis in Medicine, ten lectures, open to physicians only. This course is approved by the Committee on Medical Education of the New York Academy of Medicine. The lecturers are: Drs. Brill, Feigenbaum, Kardiner, Lehrman, Lorand, Meyer, Oberndorf and Zilboorg. (2) Popular Lectures on Psychoanalytic Topics, eight lectures, open to the public. The lecturers are: Drs. Brill, Kenworthy, Lehrman, Meyer, Oberndorf, Williams, Wittels and Zilboorg. (3) Pedagogy and Psychoanalysis, fifteen lectures, open to teachers. This course is accredited by the New York State Department of Education and accepted by the Board of Education of New York City for "alertness credit." The lecturers are: Drs. Brill, Broadwin, Meyer, Oberndorf, Shoenfeld and Williams. (4) Introductory Course in Psychoanalysis, ten lectures, open to social workers, jurists, theologians and members of allied professions. The lecturers are: Drs. Brill, Glueck, Meyer, Oberndorf, Shoenfeld and Williams. (5) Intermediate Case Discussion Course, open to social workers who have completed course 4 or its equivalent. The lecturers are Drs. Glueck, Kenworthy, Stern and Williams. (6) Advanced Seminars for Social Workers, round table discussions, open to experienced social workers. The attendance is limited to twenty per section. The lecturers are: Drs. Shoenfeld, Stern and Zilboorg. For further details, apply to the Executive Director, the New York Psychoanalytic Institute, 324 West Eighty-Sixth Street, New York.

Abstracts from Current Literature

PAPILLEDEMA. W. E. FRY, Arch. Ophth. **6**:921 (Dec.) 1931.

This article is an ophthalmologic review of the subject. The various theories as to the basis of papilledema are discussed in detail. They have been of particular interest to ophthalmologists for a long time, and the literature on the subject is large. The present review is limited to contributions that are particularly concerned with the method of formation and the pathology of papilledema.

The theories in regard to the formation of papilledema may be divided into the mechanical and the nonmechanical types. The mechanical types are concerned with an interference with either the flow of lymph or the vascular supply of the optic nerve, and the nonmechanical types with either an inflammatory reaction or a toxic agent. It is of historical interest that the first theory advanced by von Graefe in 1860 was mechanical in its view. The first nonmechanical theory was presented in 1879 by Gowers, who formulated an inflammatory theory, and in 1881 by Leber, who believed that the development of papilledema was due to toxic material from intracranial disease.

Briefly, the mechanical theories were those of Graefe, who based the disease on venous engorgement due to pressure on the cavernous sinus. He abandoned this opinion when Sesemann demonstrated the free anastomosis that exists between the ophthalmic and facial veins. Recently, the theory of the rôle of the intracranial venous sinuses as an etiologic agent has been revived by Swift. Schwalbe, in discussing this, demonstrated the connection between the subarachnoid spaces of the brain and the optic nerve. Schmidt further demonstrated by injection methods a complete filling of the lamina cribrosa. He believed that papilledema was due to this edema, by the fluid forced in at the lamina cribrosa, and that this in turn caused an incarceration of the intra-ocular end of the optic nerve. Schmidt-Rimpler confirmed this opinion.

Manz was not able to demonstrate a system of lymph canals in the lamina cribrosa that communicated with the subarachnoid space. Since the nerve sheath was distended by the fluid under pressure, he formulated an explanation of papilledema based on compression of the central vessels of the retina as they passed through the lamina cribrosa. Bordley and Cushing seem to have confirmed the work of Manz, and in part that of Schmidt-Rimpler. In their experiments, fluid was introduced into the subdural space under pressure. When the fluid pressure was in excess of the venous pressure, a venous engorgement appeared in the retinal veins and a measurable amount of swelling of the papilla was produced. If the pressure was made more nearly equal to the arterial pressure, a high grade of venous engorgement resulted with a high swelling of the disk. In other experiments, the nerve sheath was ligated distally to the chiasm and sufficient pressure was used to cause a venous obstruction without interfering with the arterial circulation. In these experiments only venous engorgement occurred and no swelling was apparent. From these experiments Bordley and Cushing did not believe that venous stasis alone is capable of producing papilledema.

Rochon-Duvigneaud, Liebricht and Schieck based the formation of papilledema on the development of a block in the lymphatic drainage of the optic nerve. Levinsohn opposed this view, but advanced the theory that the swelling of the disk is due to checking of the outflow of the lymph from the vitreous cavity. The results of the work of Berens, Smith and Cornwall agree closely with those of Levinsohn. The work of Sweet, Gifford and Wegefarth seemed to prove that there is lymphatic drainage from the eyeball along the central vessels, and it is believed that blockage of this drainage is an important factor in the production of the edema.

Saenger and Behr based their theories on pressure on the optic nerve as it traverses the optic foramen. This causes an interruption of the lymph flow with a consequent papilledema. Foster Kennedy demonstrated the untenability of the theory of this mechanism from a series of cases of tumors of the frontal lobe in which pressure on the optic nerve led to retrobulbar neuritis with a central scotoma and primary atrophy of the optic nerve in the eye on the side of the lesion and with papilledema in the eye on the opposite side. While Behr adopted the view that there is compression of the nerve at the opening of the bony canal he believed, in addition, that the lymph stasis in the sheath compressed the central vein in the nerve with the production of venous congestion and hence engorgement of the vessels of the fundus.

Lillie, in a discussion of a paper by Swift, stated that in his opinion Behr's theory solves the clinical problems of papilledema better than does any other. Deyl, who made serial sections of the optic nerve in a case of papilledema, found distention of the intervaginal space with acute bending and compression of the vein as it entered the dura. Knape also described compression of the vein by an edematous swelling of the dura. He did not believe that this was constant, because of the disappearance of the edema and pressure after death.

The observations of Dupuy-Dutemps were first made from an examination of one eye in each of three cases of tumor of the brain. He believed that the compression of the central vessels took place in the intervaginal space. Merz produced choked disk in rabbits by the subdural injection of a saline solution. The optic nerves, when sectioned, showed compression of the central vessels as they passed through the intervaginal space. Paton and Holmes, who studied sixty eyes, expressed the belief that the primary factor in papilledema is a local increase in the venous pressure in the central vein. They stated: "In our opinion, therefore, the edema of the papilla that constitutes tumor papilledema is, in the first place, due to the venous engorgement that results from the rise of intravenous pressure that is necessary in order that circulation should be maintained in the intervaginal portion of the vein where this is subjected to an increased sheath pressure." Foster Moore believed that compression of the central vein in the subarachnoid space is one most acceptable theory.

The nonmechanical theories are those of Gowers and Leber, Deutschmann, Lawford and Edmunds. Elschnig and Scimeni believed that inflammation is developed, with edema and infiltration, as a result of toxic material from intracranial disease. Sourdille and Kampherstein believed that a forward extension of an edematous process orginating in the brain is the cause. Sourdille believed that the fluid is forced from the third ventricle over the chiasm and into the optic nerves: these nerves become swollen and are strangulated in the foramina, with resulting venous and lymph stasis of the papilla and the optic nerve. Kampherstein believed that edema of the brain extends into the optic nerve through the lamina cribrosa into the papilla, and produces incarceration of the intra-ocular end of the nerve.

A disturbance in the vasomotor system has been assumed as the cause of the swelling of the disk by various authors. Benedict incriminated pathologic changes in the sympathetic nervous system. Loring and Hughlings Jackson thought that there is compression of the nerves that control the circulation and nutrition of the optic nerve. Adamkiewicz regarded the condition as a neuroparalytic inflammation. Kornder was able to produce papilledema in six of a series of ten dogs, in from three to ten days, by the injection of 1 cc. of melted paraffin through a trephine opening in such a way as to block the aqueduct of Sylvius. He did not believe that the increased venous pressure, shown by an engorgement of the retinal veins, was due to a local cause such as direct pressure on the nerve structure or the central vessels, but thought that it was a local manifestation of high venous pressure in the whole body. As a result of the high venous pressure in the retinal veins there occurs an excessive transudate of lymph into the disk and retina. In regard to a vasomotor etiology, he said: "Whether this high venous pressure is entirely due to the accentuated inhibitory action of the vagus consequent to

central stimulation from the high cerebrospinal fluid pressure may be a question open for further investigation."

Fry gave also a list of miscellaneous theories other than mechanical or non-mechanical. Tilney suggested anatomic changes in a small canal extending from the third ventricle above the optic nerve and chiasm. Parker performed an operation with an Elliot trephine on one eye of an animal; after the opening made by the trephine had healed the intracranial pressure was increased; the nerve of the eye with the lower tension was the first to show papilledema, and when papilledema appeared in both eyes, the eye with the lower tension showed the higher swelling. Meyer had previously recorded clinical evidence that pointed in the same direction. Rados first presented clinical observations that papilledema frequently appears first on the side on which the brain is involved. He confirmed this experimentally.

The pathologic changes in papilledema have been studied by many investigators (Kampherstein and Elschnig, Paton, Parsons and Holmes). Kampherstein and Elschnig showed that the subarachnoid space is filled with a coagulated exudate, and in the more chronic cases with an endothelial proliferation. However, in the opinion of Paton and Holmes this was not sufficient to cause compression of the nerve. The distention of the sheath is usually several millimeters behind the globe. The disks themselves showed edema of the lamina cribrosa, causing a wide separation of the nerve fibers of the disk and extending into the nerve fiber layer of the retina for as much as one diameter of the disk. The retina adjacent to the disk is displaced laterally, and sometimes with it the pigment layer, which may be thrown into a series of elevations. The normal uniform curve of the fibers is changed so that the more laterally placed fibers take an S-shaped course. Paton and Holmes found that in severe cases the internal limiting membrane near the disk is raised in small elevations. These contained an exudate and are traversed by stretched or ruptured fibers of Müller. They are seen more frequently on the macular side of the disk.

Edema of the intra-orbital part of the nerve was noted by Kampherstein in 60 per cent of his cases. He found the edema to be characteristically interfascicular in location. Paton and Holmes noted in this regard that there is a definite difference between the vessel-bearing portion of the nerve and that part behind the entrance of the central vessels. Dupuy-Dutemps formulated a theory based on a difference in the edema as it appears in each vessel-bearing portion of the nerve in that part beyond the entrance of the central vessels. A subpial edema, often marked, was emphasized by Paton and Holmes. On the other hand, Ulrich stated that subpial edema is seldom found.

In the denser posterior layers of the lamina cribrosa, no alteration in position or separation of the fibers has been noted. The anterior layers of the lamina, corresponding to the pars choroidea, are carried forward to form an arc convex anteriorly, and the fibers are so stretched and separated that this layer is recognized with difficulty. Attention was first called to this by Schweigger. Elschnig, who found this feature in 91 per cent of his cases, thought it the most constant anatomic difference between papillitis and papilledema. Kampherstein found it in 79 per cent of his cases and Liebricht in all of twelve cases.

Most observers have found that the inflammatory changes in cases of recent papilledema are scant. There may be a slight small round cell infiltration in the connective tissue about the central vessels, and a wide dilatation of the vessels of the swollen papilla, with hemorrhages, both along the vessel sheaths and just beneath the internal limiting membrane.

The degenerative changes have been divided by Paton and Holmes into a primary and a secondary type. The primary type is most marked near the surface of the swelling and in the lateral bulging of the nerve fibers. By ordinary stains the fibers were seen as opaque homogeneous areas. Paton and Holmes described in the disk "cystoid bodies" similar to those found in the retina in albuminuric retinitis, in vascular lesions and in the region of local injuries. These were described as "varicose degeneration of the nerve fibers." After a certain stage of development, they undergo fatty degeneration, so that they are not seen in

the later stages of papilledema. The secondary degeneration was seen as a crescentic area on the edge of the nerve. These areas have been studied and importance has been given to them by Behr. In the later stages of papilledema there is proliferation of neuroglial tissue, with a gradual shrinkage of the tissue of the swollen disk.

SPAETH, Philadelphia.

ZONA. ANDRÉ THOMAS, Rev. neurol. **2**:737 (Dec.) 1931.

In the symposium on the acute infections of the nervous system at the International Neurological Congress in Berne, Thomas presented, in abstract, an important summary of the knowledge of herpes zoster. He points out that this is not a disturbance limited to the skin. "The eruption is preceded, accompanied or followed by nervous disorders of different varieties which indicate that the disease affects the nervous system as well as the integument. To these cutaneous and nervous symptoms are added, in certain cases, symptoms of general type that belong to the symptomatology of general infection."

Symptoms indicative of infection are malaise, mild fever, general fatigue and gastro-intestinal upsets, although more severe symptoms are not unusual. These symptoms, however, with pain in localized areas and enlargement of the glands, may be diagnosed as herpes zoster before the eruption occurs, and even in the absence of an eruption. The pains are more apt to affect aged persons, although the eruption may predominate in young ones. The nerves are sensitive to pressure, and the skin shows various disturbances of sensibility, sometimes increased, sometimes decreased, possibly dissociated.

The affection of the cranial nerves is of particular interest on account of complications. In zoster of the ophthalmic branch there may be neuroparalytic keratitis; in affections of the geniculate ganglion, facial paralysis and acousticovestibular symptoms may be present, whereas affections of the bulbar ganglia may produce eruptions in the pharynx and larynx. Paralysis of the limbs is uncommon. Paralysis of the face is fairly common, but does not always occur on the side of the pain. Symptoms referable to the vegetative nervous system are practically always to be found, and Thomas devotes a section to their study. Vasomotor and sudomotor disturbances are common. The pilomotor reflex may be particularly active or inactive in certain parts, and this may last even for a number of years. The eruption may be very mild or if it becomes infected may produce severe sloughing with marked scarring. Study of the spinal fluid reveals a meningeal reaction, with increased globulin and cell count in about half the cases. This may last for a number of months. Symptoms of meningeal irritation are seldom present.

The cutaneous eruption is extremely variable in extent, sometimes picking out a single root, sometimes spreading over a large area. Recurrences are common and usually take place in the same location, although symptomatic zoster must be considered here. Occasionally, a generalized eruption is associated with the shingles, and a differential diagnosis between that and chickenpox is often difficult. Encephalitis following zoster has occasionally occurred, with rapid death.

The pathologic process is located principally in the skin and in the dorsal root ganglia. The cutaneous lesions are characterized principally by the large vesicular cells of Unna and lymphocytic invasion with epithelial necrosis — a somewhat different picture from that found in febrile herpes. The lesions in the ganglia are characterized by marked lymphocytic infiltration, hemorrhage and degeneration of the cells, nerve fibers and dorsal roots. The lesions in the ganglia can differ in different areas and at different times, and the inflammation is particularly pronounced about the vessels. The ganglion cells disappear, and the capsular cells proliferate. The axis-cylinders may swell from ten to fifty times their normal caliber, and the sheaths are swollen and irregular and show wallerian degeneration. Milder lesions often occur in neighboring ganglia. Secondary degeneration occurs in the central and peripheral ends of the nerves, and this degeneration is followed by attempts at regeneration. The spinal cord is affected in such a way that the name posterior poliomyelitis is given, and the lesions may be much more diffuse

than those in the ganglia, extending even to the brain stem and basal ganglia; they are hemorrhagic and chronic. The leptomeninges are inconstantly infiltrated by lymphocytes. In exceptional cases the spinal ganglia are spared.

Zoster is not a common communicable disease. Its relationship to various diseases is traced. It seems particularly common in syphilis; it has been observed in cases of encephalitis, but in meningitis and pneumonia it is very rare, while herpes is extremely common. Varicella has been contracted by many patients in contact with patients with zona, and several arguments are given on either side of the question as to whether the two conditions are caused by the same agent. These arguments embrace the period of incubation, crossed immunity and complement fixation, as against differences in contagiousness and inoculability. Zona might be an example of mutation similar to that observed between Brill's disease and typhus.

The differences between zoster and herpes are somewhat more marked, especially since herpes seldom or never leaves scars and lesions of the nervous system in human herpes are unknown. The blister fluid in zona will produce nothing in animals, whereas that in herpes will produce encephalitis, and herpetic inoculation may be positive in a patient with zona.

The portal of entry of the virus and the pathogenesis of the eruption are discussed, the former being largely unknown; the latter again points to the close relationship between the neuraxis and the ectoderm. The reason why zoster does not spread is probably because of rapid development of immunity.

Therapy is directed particularly at the severe pains, and surgical intervention has sometimes been substituted for medicine, but too often without result on account of the lesions in the ganglia, the roots and the nerve centers themselves.

FREEMAN, Washington, D. C.

SPECIAL DISABILITY IN SPELLING. SAMUEL T. ORTON, Bull. Neurol. Inst., New York **1**:159 (June) 1931.

The author emphasizes the fact that a large part of early academic education is, from a neurologic standpoint, a building up of associations between visual symbols and previously acquired auditory memories for words. The author's previous work on reading disabilities is reviewed in some detail, with a clear account of the neurophysiologic mechanisms involved. The opinion is advanced that the plan of bilateral fusion seems to be the rule in audition, as well as in vision, and failure in the development of complete dominance of one hemisphere is stressed as an important factor in the production of reading and spelling disabilities. Left-handedness is considered in some detail, and the selective use of the right hemisphere in control of highly skilled movements is considered a recessive hereditary character. Language disturbances, as evidenced by delayed speech, stuttering, strephosymbolia and pathologic writing, occur most frequently in families in which left-handedness occurs. The predominance of such difficulties in the male over the female indicates a partial sex-linked type of heredity rather than the strict mendelian distribution. The various disabilities in language acquisition show a common failure in building up rapid and accurate associations between the various sensory engrams. The chief cause for this difficulty lies in the condition the author terms "strephosymbolia," which is characterized by confusion between a given symbol and its mirrored counterpart, by a tendency toward reversal of direction in reading, so that words are read in part or as a whole and to the left instead of to the right, and by a facility in mirror reading. All of these symptoms stand in fairly definite quantitative relationship to the severity of the disability produced by the lack of cerebral dominance. While the most serious disability usually manifests itself in failure to acquire reading ability and in defective spelling, which is frequently associated with this condition, in some cases the reading ability is comparatively good, while the disability in spelling is the outstanding feature.

Inquiry into the nature of this problem is the objective of the author's study. He emphasizes the importance of accurate diagnosis of the character of the faulty

associations that cause the spelling disability, as this must form the basis of rational reeducation. Analysis is made by tests of auditory acuity and of auditory differentiation by having the subject repeat letters of the alphabet and monosyllabic words and nonsense syllables. The words are gradually increased in length, and, as the patterns offered become larger, the difficulty in reproduction becomes obvious. Studies of spelling defects, both written and oral, show two major types of reversals: first, a static orientation defect indicated by defective orientation of individual letters, such as confusion between the *b*, *d*, *p* and *q* types, and, second and most important, the reversals in direction of progress, which the author terms "kinetic reversals," e. g., "wram" for "warm," etc. Phonetic defects are apparently important factors in persons showing spelling disability, and for this type of child training in fundamental phonetics is of decided importance. The simultaneous tracing over a pattern while saying the name and the sound of the letter are recommended to establish the association between the name, sound and proper orientation; particularly is this true for reversible figures. In the forms showing kinetic reversals a grounding in phonetic equivalence of individual letters should be followed by training in syllabic synthesis of long words. As an aid to this, following with the finger or pointing with the pencil is highly recommended. Older persons frequently find it difficult to go back to lessons in the alphabet. In such cases oral reading, with emphasis on the accuracy of enunciation, has been found to be of great value. This should be done by reading aloud to a parent, teacher or tutor who has a good ear for pronunciation and stresses accuracy. It is well to overstress on the muted sounds of words, as such emphasis serves to fix certain letters in memory and does not carry over into ordinary speech. Methods of testing, types of errors and retraining methods are outlined in considerable detail; the article must be read in order to appreciate the sound contribution which the author makes to the understanding of this subject.

KUBITSCHEK, St. Louis.

STUDIES OF LIVING NERVES: I. THE MOVEMENTS OF INDIVIDUAL SHEATH CELLS AND NERVE SPROUTS CORRELATED WITH THE PROCESS OF MYELIN-SHEATH FORMATION IN AMPHIBIAN LARVAE. CARL CASKEY SPEIDEL, J. Exper. Zool. **61**:279 (Feb. 5) 1932.

Individual sheath cells of Schwann and nerve sprouts were watched for long periods (ten to one hundred and eighty days) in the tail fin of the living amphibian larva (Hyla, Rana and Triturus). After early development of the frog tadpole, the nerves of the tail fin are partly unmyelinated and partly mixed. In the unmyelinated type and in the unmyelinated portion of the mixed type, there may be distinguished "myelin-emergent" fibers and "nonmyelin-emergent" fibers. The former differ from the latter in their greater bias toward myelin formation, and in combination with a primitive sheath cell lead to the formation of a new myelin segment. The latter ordinarily do not.

The transfer of a primitive sheath cell to a myelin-emergent fiber may be effected in a variety of ways, such as: from the unmyelinated portion of a mixed nerve to the accompanying myelin-emergent sprout; from a nearby unmyelinated nerve, following a temporary anastomosis where the two nerves cross; from one nerve to the unmyelinated portion of an adjacent nerve by way of an anastomosis, followed by transference to the myelin-emergent fiber accompanying the second nerve. In each, sheath cell migration may be in a distal or proximal direction and multiplication by mitosis may take place. Transfer from a cranial nerve branch to a spinal nerve has also been seen. The transfer of a primitive sheath cell from a myelin-emergent fiber to a nonmyelin-emergent fiber is quite rare. Transfer from one myelin-emergent sprout to another does take place.

Myelin formation proceeds from proximal to distal, each new unit being added at the end of the myelin line, but occasionally gaps are left, which may become myelinated by the intercalation of additional myelin segments. The earliest myelin is formed in the vicinity of the sheath cell nucleus, growing from this center by

extension in both directions. One adult internodal segment genetically corresponds to the zone influenced by one primitive sheath cell. Early unmyelinated nerves serve to direct, in a general way, advancing myelin-emergent nerve sprouts and to furnish them with primitive sheath cells as a preliminary step to myelination. The acquisition of sheath cells by the sprouts is expedited by their movemens in extension, retraction and in branching and by the formation of temporary anastomoses with adjacent fibers. Young myelin segments grow both in diameter and in length. Complete elimination of side sprouts occasionally occurs as the myelin segment becomes longer. Overproduction of myelin is frequently to be seen at the region of the node of Ranvier. Long myelin segments may be formed by end-to-end anastomosis of shorter segments, with obliteration of the intervening node. This accounts for the wide variation in length of myelin segments, and for the presence of two sheath cells on a single segment. Occasionally, a portion of one segment fuses with the segment next to it, a new node then developing. The formation of perpendicular myelin units, at a node or at a nerve terminus, is essentially like the formation of parallel myelin units.

Regeneration of a myelin segment following traumatic degeneration may occur without preliminary multiplication of sheath cells and migration. Sprouts from myelinated fibers grow into newly regenerated regions much less rapidly than do sprouts from unmyelinated fibers. Primitive sheath cells appear to aid nerve sprouts in surmounting slight obstacles in the way of free growth. Growth and extension of nerve sprouts seem also to be stimulated by sheath cell mitosis near the nerve terminus.

Other observations include detailed movements of primitive sheath cells in mitosis, extremes of variability in primitive sheath cell migration and the shifts in position of mature sheath cells on myelin segments.

WYMAN, Boston.

SPASMS OF FUNCTION IN EPIDEMIC ENCEPHALITIS. HENRI ROGER, Rev. d'oto-neuro-opht. **9**:697 (Nov.) 1931.

Most infections of the nerve centers, especially syphilis, determine paralyses localized on one side of the body, or there may even be diplegias due to two lesions of corresponding parts of the two sides of the brain. There is another type of paralysis, paralysis of function, in which not all the movements controlled by certain nerves but only certain acts pertaining to a determined function are paralyzed, as in Parinaud's syndrome. Such paralyses depend on lesions of the mesencephalon and are frequent in encephalitis. Likewise, the same muscle groups are still more frequently involved in spasms during the late stages of epidemic encephalitis. Oculogyric spasms are the most common, and they are often accompanied by other muscular spasms. Associated with them are labyrinthine, vegetative and psychic disturbances. A curious example was presented by a man who, when the ocular crises occurred, would be petrified in the attitude in which he happened to be and who was unable, during several minutes, to make any voluntary movement.

Facial, cervical or thoracic spasms may exist separately or be associated with these ocular crises. Among the facial spasms are: palpebral occlusion, orbicularis spasm, bilateral facial paraspasm (perpetual grimace), spasms of mastication and of the lips, of the tongue and, rarely, of deglutition. Rhythmic contractions of the palate, improperly called nystagmus of the palate, are often discovered in the course of a clinical examination.

Among the cervical spasms are: spasmodic torticollis, spasms of phonation, varying from aphonia due to hypertonia of the vocal muscles to palilalia, paroxysmal tachyphemia (homolog of paradoxical kinesia) and stammering.

Thoracic spasms of function are represented by disturbances of the respiratory rhythm (more common in children), paroxysmal polypnea, which occurs toward nightfall, spasmodic cough and respiratory tics (blowing, sniffing, spitting, barking and laughing).

In spite of the diversity of their semeiology, all of these spasms are characterized by the affecting of bilateral muscle groups and by the habitual exercise of

a synergistic (sometimes antagonistic) action. They eventuate in not a common tonic or clonic spasm but a movement corresponding to a given function. They are often excited by emotional shocks and are ameliorated by repose and sleep.

The physiopathologic basis of paralyses and spasms of function is thought to be a lesion or irritation of the association fibers between the nuclei of origin of corresponding nerves. The location in the mesencephalon and myelencephalon of these nuclei and association tracts close to each other explains the association of several kinds of spasm in the same patient at the same or diverse periods of the disease. The rapid appearance and disappearance of the crises suggest a vasomotor disturbance. Their extreme rarity in other diseases of the nervous system gives them considerable importance in etiologic diagnosis. They are found especially in the late stages, usually associated with an indistinct parkinsonism. They have medicolegal value when they occur in young subjects, and their correct interpretation often serves to correct a previous erroneous diagnosis.

Therapy is disappointing. Besides rest and sleep almost nothing abates the crises, though datura and scopolamine hydrobromide, singly and in combination, have been of use. The antagonistic gesture in spasm of occlusion of the lids (raising the brow with the finger or by a spring on a spectacle frame) is at times efficacious. In torticollis, surgical intervention on the sternocleidomastoid muscle or on the external branches of the spinal accessory nerve gives relief at times. In a case of spasm of protrusion of the tongue, Lhermitte made a partial bilateral resection of the hypoglossal nerve in one patient. After a period during which the patient had to be fed by a tube, deglutition became normal and the lingual spasm was considerably abated.

Dennis, Colorado Springs, Colo.

Blindness and Papilledema in Guernsey Calves, Usually Bulls. G. E. de Schweinitz, Arch. Ophth. **7**:1 (Jan.) 1932.

This article has been reviewed because of the pathologic changes in the optic nerves.

According to de Schweinitz, it appears that there exists among calves, usually, if not exclusively, of the Guernsey breed, a disease characterized by blindness, the onset of which is, as a rule, sudden, commonly occurring within the first year of life. Other symptoms, general as well as neurologic, are lacking. The blindness is permanent, and the papilledema, or papillitis, is not caused by gross intracranial disease, such as tumor, encephalitis, meningitis and the like. The animals develop naturally, grow fat and, as far as is known, do not transmit the disorder to their progeny. They seem to belong to a special group, and the disease with which they are affected should probably be regarded as a clinical entity.

From a pathologic standpoint, Nettleship and Hudson advanced the opinion that a toxic agent, acting through the blood stream, produces a subacute poisoning, of unknown origin, which acts selectively on the retinas and optic nerves. From a careful study of de Schweinitz' slides, Verhoeff states: "I judge that papilledema has existed for a long time, and must have been of high grade, but not sufficient to cause retinal hemorrhages. It has lasted long enough to cause marked proliferation of the neuroglia of the disc, thus converting the disc into a tumor-like mass incapable of shrinking to its original size. The decided atrophy of the optic nerve fibers is in accordance with long duration of the papilledema. The absence of definite edema of the disc indicates that the cause of the choked disc had ceased to act at the time the eye was removed. The absence of any evidences of past or present inflammation indicates that the cause of the papilledema was increased intracranial pressure, probably not of high degree but of long duration. The possibility, however, that the papilledema was due to preexistent, slight inflammation of the nerve, with marked edema, is not positively excluded." A recent article, reviewed in the Archives of Neurology (Fry, W. E.: Papilledema, *Arch. Ophth.* **6**:921 [Dec.] 1931), discussed in detail the etiologic factors connected with papilledema, including the mechanical factors and the toxic and inflammatory changes. This form of bovine blindness appears to be a special or familial disease

that depends largely on inbreeding, which predisposes the animal to its salient manifestations. Blindness ultimately develops, as a result of the choked disk, which is due to either papilledema or papillitis, with ultimate destruction of the ganglion cells of the retina and extensive degeneration of the apparatus of the optic nerve as far back as, and including, the chiasm. De Schweinitz describes in detail the histories of six cases and gives a brief report of a seventh. In discussing the etiology, he considers food poisoning, familial papilledema or papillitis, and inbreeding. He quotes Nettleship and Hudson relative to a suspicion that the disease of the optic nerves is the result of an hereditary disposition, analogous to the well known familial optic neuritis of a young man, Leber's disease, which may appear for a number of generations, usually, but not always, in male members of the family, and is generally transmitted by unaffected females. De Schweinitz states that, as far as he knows, in his series of cases none of the blind bulls transmitted the disease to their progeny, but he adds that his evidence in this respect is definitely imperfect.

The article is well illustrated with photomicrographs of the pathologic histology of the condition.

Spaeth, Philadelphia.

Histology of the Cerebral Peduncle in Cuttings Made Opposite Point of Emergence of Common Oculomotor Nerve in Encephalitis with Paralysis of That Nerve. D. Anglade and P. Lassalle, Rev. d'otoneuro-opht. **9**:750 (Dec.) 1931.

This article deals with the histologic results of examinations of the cerebral peduncle of subjects who died after having presented the sequelae of paralysis or paresis of the common motor oculi nerve. The sections were stained by the method of Nissl, as modified by Anglade, for nerve cells, by that of Mlle. Loyez for myelin and by that of Anglade for the neuroglia.

Anglade and Cruchet, in 1917, described the formation of nodules in the nuclei of origin of the third nerve and in other gray or black masses in the mesencephalon in cases of paralysis occurring in the acute stage of encephalitis. The resemblance of these formations to those in rabies was striking. It remained to discover what becomes of the nodules during the further evolution of the disease.

The most important and constant lesions, aside from those of the nuclei and fibers of the nerve, are in the locus niger. In one case, these lesions had progressed to destruction and replacement of the black substance by a neuroglial cicatrix, which surrounded the greater part of the nerve fibers of the third nerve. The red nucleus is also traversed by fibers of the third nerve, but the authors have not found here the lesions mentioned by others. At the most they found a cellular chromatolysis and rarefaction, which was not accompanied by a gliosis of replacement. The next most important lesions are those of the nuclei of origin of the third nerves. They appear in two forms. In the first, the nuclei are invaded by numerous giant, polymorphonuclear astrocytes, and the nuclei themselves are reduced in size, are rounded and are loaded with pigment. These nerve cells are attached to the astrocytes, the fibers of which surround them like tentacles. In the second, the nuclear groups are embedded in a mass of gliosis, a true neuroglial sclerosis "*en plaque*." They appear in balls or spindles; their prolongations are cut off, and the nuclei and chromatin have disappeared. These strands of gliosis join the subependymal neuroglia stratum, which is itself thickened.

The sections showed also thickening of the neuroglia around the peduncles and the quadrigeminal bodies, the latter standing out in deep blue. A tendency of the gliosis to encroach on the posterior longitudinal bundles was noted.

It appears, therefore, that the oculomotor pathways are damaged in their nuclei of origin, their intrapeduncular course and, notably, above their point of emergence at the level of the most internal segment of the locus niger. The most important are the lesions of the nuclei of origin; next, those of the fibers that traverse the locus niger. Logically, one might assume a bond of continuity between the initial nodular form and the ultimate glial state, but this is not confirmed clinically.

It is believed that the virus attacks primarily the nerve cells and secondarily awakens a pathologic activity of the neuroglia at particularly sensitive points. The oculomotor pathways do not suffer total destruction, which accounts for the fact that true paralyses are not found. The transitory and capricious character of certain phenomena — spasms, myoclonias, etc. — is explained by this fact and by the fact that the nerve elements are disturbed in their action by the processes going on in the neuroglia. It seems that what takes place in the peduncle resembles a little what occurs in the gray nuclei in chronic chorea and in multiple sclerosis. In fact, the question has previously arisen as to whether multiple sclerosis is not a very special form of epidemic encephalitis.

Dennis, Colorado Springs.

Parenteral Use of Liver Extract in Pernicious Anemia. William P. Murphy, J. A. M. A. **98:**1051 (March 26) 1932.

The author treated thirty patients with pernicious anemia by means of liver extract administered parenterally. The extract may be administered easily and safely either with or without hospitalization of the patient and with the greatest assurance of success. Improvement in the blood is even more rapid and striking than that to be expected from the ingestion of much larger doses of liver or potent liver extract. Treatment was followed by an increase in the reticulocytes (young red blood cells) generally within a shorter period than occurs after treatment by mouth, and the numbers of the erythrocytes have increased promptly in practically all cases treated, even in those patients who were considered to be somewhat resistant to improvement to liver or extract given orally. There was a prompt and often very striking increase in the number of the white blood cells and blood platelets within a few hours of the beginning of treatment and a continuance of a normal or slightly elevated level during the course of treatment. Symptomatic improvement occurred after parenteral treatment, as is to be expected following the satisfactory oral use of liver or liver extract, although the improvement in general well being of the patient possibly occurred sooner after the onset of the former treatment than when oral treatment is used. Improvement in symptoms resulting from the damage to the spinal cord was striking in the patients whose treatment had been most satisfactorily carried out. The extract was administered to the series of patients without a reaction of importance. It may be advisable, as has been done in some of the patients with whom this report deals, to test all cases with one or more small preliminary injections in order to avoid the possibility of a severe reaction in the rare patient who may be hypersensitive to the liver. The most satisfactory use of parenteral treatment is the intramuscular injection of large or optimal amounts of the liver extract (extract prepared from 300 to 400 Gm. or more of liver) during the beginning of the treatment of a patient in relapse. Subsequent and maintenance treatment may perhaps best be carried out by similar smaller injections at intervals varying from five to seven days, or even much less frequently in the uncomplicated cases. The exact interval must be determined by the condition of the blood and that of the patient. Although the injections may be given daily, such treatment will rarely be indicated, and it has been generally less well received by the patient than treatment at less frequent intervals. The rapid effect, together with the ease and safety of administration of the extract, especially intramuscularly, makes it an invaluable means of treating the critically ill patient and may well replace the use of either transfusion or stomach tube in the treatment of such a patient. The injection method of treatment should be a valuable substitute for the oral method in the patient who finds difficulty in the constant ingestion of a sufficient amount of liver material or whose gastro-intestinal tract is upset thereby, with resultant gas, discomfort or diarrhea. In the latter group the injections may be used permanently or for periods of a few weeks, alternately with liver or extract by mouth. In fact, such an alternation of methods may be desirable during the maintenance treatment of many patients who now find little or no difficulty with the oral regimen. Finally, mention is made of the economy possible through the use of parenteral extract as compared with the expense of either liver or liver extract administered orally.

Editor's Abstract.

Myoclonus of the Palate. G. Guillain and T. Mollaret, Rev. neurol. **2:** 545 (Nov.) 1931.

Two cases with somewhat unusual clinical features are reported. The first patient, aged 55, experienced a disturbance in speech in the fall of 1928, and the year previous had suffered two attacks of vertigo with sensations of falling backward. In speaking, his words were broken off abruptly, and examination of the throat showed rhythmic twitching of the palate at the rate of 120 per minute. The posterior wall of the pharynx likewise presented slight twitching movements, and similar ones were observed about the orifice of the eustachian tube. Synchronous movements were also observed in the two vocal cords, the twitchings taking place in abduction, but these movements were arrested by phonation. Voluntary motility was not affected; reflexes and the sense of taste were preserved. Nothing else was observed in the neurologic and general examination, although the Wassermann reaction was positive in the blood. Observation a year later revealed extension of the myoclonic syndrome. The movements had extended to the eyeballs where, in addition to ordinary nystagmus, there was a rapid oscillatory rhythm of about 200 per minute, and there was also rotatory oscillation at the rate of 120 per minute of continuous character. Slight twitching about the right corner of the mouth was observed, but none in the tongue or in the mouth, subhyoid or intercostal muscles. The diaphragm, however, was affected by the same twitching movements. Aside from slight reduction in the intensity of the myoclonus by cicutine, treatment brought about no change. In October, 1930, the syndrome had extended more markedly to the larynx and other muscles of the neck, and also to the intercostal muscles on the left side. A mild pseudobulbar syndrome had developed, with disturbance in swallowing and phonation, exaggerated emotional responses and stiff uncertain gait; the plantar reflex was in extension on the left side.

In the second patient, aged 60 years, the process began more abruptly, with right hemiplegia, not involving the face, and tending toward recovery. Examination revealed mild hemiplegia with disturbances in language, fairly marked cerebellar signs and fleeting lateral nystagmus, but without sensory changes. The patient tended to laugh a little inordinately. Myoclonic movements of the palate, at the rate of 130 per minute, were observed on the right side, interrupted by voluntary movements and associated with similar movements of the pharynx and larynx. The dome of the diaphragm on the right side presented similar movements, but there were none in the cervical region. The blood pressure was markedly elevated; the Wassermann reaction was negative. During the succeeding months the condition became aggravated, with the occurrence of one or more slight strokes, which affected the left side and completed the picture of pseudobulbar paralysis with spasmodic crying. Myoclonus had now become bilateral, and there was, in addition, disturbance in sensibility to pain and temperature on the left side of the body, indicating a lesion in the brain stem.

In most of the instances of palatal myoclonus there has been found degeneration of the central tegmental fasciculus of the pons, but in some cases this is entirely normal. On the other hand, some cases have been reported in which the dentate nucleus has been decidedly affected. In all cases so far reported there has been hypertrophic degeneration of the inferior olive.

Freeman, Washington, D. C.

Peripheral Nerve Paralyses Following the Use of Various Serums: Report of Case and Review of Literature. Forrest Young, J. A. M. A. **98:** 1139 (April 2) 1932.

Young reports the case of a man, aged 40, who was given tetanus antitoxin following a small injury. Severe serum disease ensued three days later. Three days after the onset of serum disease the patient began to have severe pain in both upper extremities and, to a lesser extent, in the back and legs. Seven days

after the beginning of serum disease he noted weakness of the right arm with diminished sensibility. Six weeks after the serum disease he had an evident paralysis of the axillary nerve, with muscular atrophy and complete reaction of degeneration. After about three months of daily massage and abduction in a splint, feeble motions of the midsection of the deltoid muscle could be made out and the muscles appeared less atrophic. The author calls attention to the fact that there seem to be two clinical pictures which may follow the injection of serum. The first, and probably the more common, is that of injury to the peripheral nerves. In this group the patient receives an injection of serum often for the first time. In from four to eight days, he usually, but not invariably, has a serum reaction of an intense degree. In from two to three days more, severe pain is experienced in one or both of the upper extremities, with pain of a lesser degree in other parts of the body. In another two or three days, weakness of one of the upper extremities is then noted. Either this is followed by gradual complete recovery extending over a period of a month, or in about six weeks muscular atrophy and reaction of degeneration to electrical stimuli are noted. The prognosis in the latter group is only fair, incomplete recovery being the rule. The cases in the group showing signs of involvement of the central nervous system are on the whole much more serious as regards life. The usual clinical course seems to be as follows: The patient receives serum, generally intraspinally, in repeated doses. After a time, varying from three days to a month, and without warning, another injection is followed by a severe reaction. This is manifested usually by a generalized urticarial eruption, which is followed in a few hours by convulsions, opisthotonos, coma, high irregular pulse, irregularity in respirations and possibly death. The patient, however, may recover, and, if so, recovery is usually complete. If the cord is involved there may be, of course, residual paralysis and atrophies as in poliomyelitis. The paralyses following vaccines are too few to afford much in the way of conclusions. In general, they seem to be distinguished by the fact that they are not accompanied by serum disease, are much slower and more gradual in onset and do not necessarily show a predilection for the upper extremities. The etiologic theories considered are those of constriction of the nerves by perineural edema and direct toxicity of the serum for ganglion cells or their processes. Prognosis is determined by the occurrence of atrophy. In those cases in which atrophy is not noted in from six weeks to two months, the prognosis is good. In cases in which atrophy occurs, the prognosis is poor. Peripheral nerve paralysis following the use of serum is, however, so rare that it should in no way influence the use of prophylactic serums, but should be regarded as one of the hazards of so doing, and the patient should possibly be warned of rare untoward results.

EDITOR'S ABSTRACT.

HYSTERIA AND CONDITIONED REFLEXES. G. MARINESCO, O. SAGER and A. KREINDLER, Rev. neurol. **1**:721 (June) 1931.

The authors have recognized for some time that crises of various sorts, particularly the oculogyric crises in encephalitis, yield almost immediately to the intravenous injection of scopolamine. Moreover, the reaction takes place so quickly that they were led to substitute distilled water and noted that for a period of several injections the crises were aborted in the same way. They likened these effects to the conditioned reflexes observed by Pavlov in lower animals, and pursued their researches on patients of hysterical type. Experiments were carried out on three patients under peculiar circumstances as regards isolation, time of day and preparations for injection, and in one a phonograph record.

The first patient on three successive days received 10 mg. of morphine, which produced the usual calming effects. On the fourth, fifth and sixth days the same calming effects, with sleep lasting for from two to three hours, together with slowing of pulse rate and respiration, were observed, but on the seventh day the patient did not sleep and became restless. Morphine was given on the following day, and again for three days the injection of distilled water was followed by

sleep. Similar results were obtained in the second patient by injection of distilled water after conditioning by means of 10 mg. of lobeline. An increase in respiration from about 20 to 36 or 40 per minute was observed. The third patient, for a period of five consecutive days at the same hour and in the same isolated spot, drank two glasses of water and listened to the phonograph playing the same tune. After this, for a week, when the patient was placed in the same surroundings, hearing the same tune, but receiving no water, the diuresis was practically as marked. However, when given an interim control test without water or music and in the normal ward surroundings, he excreted only 150 cc. of urine in two hours, and the specific gravity was normal.

The authors found it impossible to establish conditioned reflexes in normal persons, at least in as short a time as that allowed for the hysterical subjects. They attempt to explain the mechanism of hysteria as a disturbance in the induction of excitatory and inhibitory processes of the cortex. Following the ideas of Pavlov, they postulate an absence of the normal positive induction surrounding a point of cortical inhibition, believing that the inhibition extends through the whole cortex, and that this would explain why hysterical patients are so easily hypnotizable. A psychic shock, they say, can bring about a generalized chronic cortical inhibition. On the other hand, in the hysterical patient there is a disturbance in successive induction, a simulation of one point of the cortex not being followed normally by its inhibition. This explains the facility with which condition reflexes develop in the hysteric patient.

In the case of the parkinsonian patient with oculogyric crises there may be partial inhibition of the cortex which would allow the operation of a physiologic mechanism of a lower order, and the disappearance of this phenomenon by verbal suggestion or otherwise would seem to be due to stimulation of the cortex. The authors ask, "Could not a lesion of the vegetative centers at the base of the brain predispose to more easy inhibition of the cortex and explain in this way the origin of certain disorders which resemble so greatly those of hysteria?"

FREEMAN, Washington, D. C.

PATHOPHYSIOLOGIC, PATHOHISTOLOGIC AND SURGICAL-THERAPEUTIC EXPERIENCES IN EPILEPSY. LUDWIG GUTTMANN, Ztschr. f. d. ges. Neurol. u. Psychiat. **136:**1, 1931.

The work of C. and O. Vogt and of Foerster on the physiology of the brain has thrown some light on the so-called silent areas of this organ and has given a clue as to the part played by these areas in the production of epileptic attacks. The encephalogram, too, has helped to demonstrate that some cases of epilepsy which were formerly considered idiopathic are due rather to hydrocephalus, to the formation of cysts or to some developmental anomaly. Guttmann reports twelve cases of epilepsy which were studied by encephalography; many of the patients were treated surgically.

The encephalogram was of great help in these cases. In cases in which the type of the attack was well known clinically, the encephalogram gave important evidence concerning the nature of the pathologic process. In other cases it was possible to secure much more information regarding the seat of the process by means of the encephalogram than by means of clinical studies alone. In still other cases in which the attack was not uniform in nature or in which there were both focal and general attacks the encephalogram gave important evidence of the location of the injury to the brain. Finally, when the attacks were not localizable or only uncertainly localizable, the encephalogram was of great significance in giving data concerning the nature and location of the disease process.

Concerning the surgical treatment of epilepsy, Guttmann says that he cannot agree with those who look on it with skepticism. If it were the only means advocated for treating epilepsy, the skepticism would be understandable, but the

surgical treatment is proposed for a limited number of cases and is not meant to supersede the medical and dietetic treatment, used in most cases.

Guttmann states that encephalography in itself often exerts a therapeutic effect on epileptic attacks. In numerous cases of epilepsy in which an operation was not considered he has seen a disappearance of the epileptic attacks for a greater or shorter length of time after the injection of air. In a case of tuberous sclerosis, encephalography was followed by a cessation of epileptic attacks for a year. In some cases the epileptic spells disappear without the use of drugs; with them the headache and other symptoms also disappear. In another group the attacks return after a varying length of time, but they can be controlled by small doses of phenobarbital. In a third group the attacks recur after the encephalography, but they can be controlled by small doses of phenobarbital, whereas large doses are needed before encephalography. The most important factor in the therapeutic effect of injection of air is the powerful stimulus that is produced on the nerve parenchyma, the vascular apparatus and the meninges. The result of this stimulus is an increased metabolic interchange between blood and spinal fluid, which causes an increased elimination of substances that produce convulsions and permits the penetration into the brain substance of materials that diminish its susceptibility to the convulsive state.

Alpers, Philadelphia.

Retinal Perivascular Delineation. John N. Evans, Arch. Ophth. **6**:823 (Dec.) 1931.

This article is a continuation of a series of papers on angioscotometry presented in 1926, 1927, 1929 and 1930. The earlier papers were based on clinical experience. The present one is the result of a series of studies, begun in 1925, to demonstrate the presence of a retinal perivascular space. The author first gives credit to and describes in detail experimental work that has been done by His, in 1867, Altmann, in 1879, Gifford, in 1886, Nuel and Benoit, in 1900, and Schneider, in 1924. He also mentions the work of Schwalbe, in 1887, of Deutschmann, in 1879, of Carl Behr, in 1915, and of Weed and Wegefarth, in 1914.

While this seems like a rather complete list, still, it was a very scanty background for a starting point of the experiments on which the author based his conclusions. Certain preliminary investigations had first to be carried out to gain familiarity with the conditions under which the ultimate investigations were made. Such factors as macerations of the cellular elements, violent distortion of the tissues and undue force necessary for the injections and many similar defects were obviated in the group of experiments. Certain other general principles in the conduct of the experiment included rigid controls, the use of only the finest needles procurable for the injections, the use of local anesthetics whenever possible, the making of the injections under ophthalmoscopic observation in live adult albino rabbits, and the estimation of the tension (in each instance) before and after the injection. It was found that when proper precautions had been observed, the variation in pressure before and after injection was negligible.

Along these lines, a tremendous amount of experimental work was done with the injection of india ink, of ocular pigments, of preparations of prussian blue and of carmine granules. The various phases of the experimental work are outlined in detail in the article and are illustrated by photomicrographs.

The author summarizes his results as follows: 1. Granules of prussian blue are found about the bipolar cells and about the ascending and descending fibers of the bipolar cells. 2. Granules of prussian blue are found about the ganglion cells and about their fibers. 3. Granules of prussian blue are found about vessels of the retina. 4. Granules of prussian blue are found about the central vessels of the optic nerve. From this evidence the author concludes that, under the conditions of these experiments, the isotonic solution when injected into the vitreous under conditions closely simulating the normal penetrates a *pericellular* and *perivascular* region. One can state only that the particles of prussian blue were

located about the vessels and cells, but must not assume that they are in a formed space, in an anatomic sense, and one must not assume that their passage from the vitreous to the retinal and nerve spaces indicates the rate or direction of the normal flow of fluid.

Spaeth, Philadelphia.

Alternating Syndrome of the Red Nucleus with Involuntary Movements of the Face and Forearm. L. van Bogaert and I. Bertrand, Rev. neurol. **1**:38 (Jan.) 1932.

A woman, aged 42, awakened, in May, 1926, with violent headache and saw double. She also suffered from vertigo. On the next day a mild right hemiplegia was present, with ataxia and falling to the right and backward. Examination showed some hypotonia on the right, especially in the upper limbs. Muscular power was conserved; the reflexes were very active on the affected side, except for absence of the achilles reflex. No Babinski sign or sensory disturbances were noted, except marked baresthesia in the upper limb. The patellar reflex was pendular on the right side, and in walking there was marked deviation toward the right. Some dysmetria was observed in the finger-to-nose test and more in the heel-to-knee test. There was no intention tremor. The right side of the face was paretic, and there were myoclonic movements of the mouth and chin on the right side at a rate of from 100 to 110 per minute and synchronous with a rhythmic normal activity. The left lid was completely ptosed, and the left internal rectus muscle showed marked weakness.

On pathologic examination, the basal ganglia were intact. A section passing above the dentate nucleus showed a focus of softening at the junction of the vermis and the right superior cerebellar peduncle. It seemed to arise in the upper regions of the fourth ventricle and penetrate deeply into the hilus of the dentate, working in between the vermis and the internal aspect of the cerebellar peduncle. Part of these fibers were destroyed close to their origin. The cerebellar nuclei were intact. The interpeduncular space was the seat of endarteritis and chronic meningitis, probably gummatous. In the section through the midbrain on the left side there was an infarct affecting the commissure of Wernicke, destroying the oculomotor nucleus and affecting the fasciculus of Meynert and the medial longitudinal fasciculus. The capsule of the red nucleus was reduced on its mesial aspect, and the whole central portion was poor in medullated fibers. This was apparently due to destruction of the superior cerebellar peduncle. The olivary body in the medulla showed early hypertrophic degeneration, especially in the dorsomesial portion. The pyramidal tract was intact.

The red nucleus syndrome in this case was very mild, since choreo-athetotic movements were absent. It would seem, however, that the rhythmic movement of the forearm was only a fragment of the tremor observed in the syndrome of Benedikt and was due to involvement of the superior cerebellar peduncle.

Freeman, Washington, D. C.

The Velopharyngolaryngeal Manifestations of Epidemic Encephalitis. Rebattu, Devic and Mounier-Kuhn, Rev. d'oto-neuro-opht. **9**:675 (Nov.) 1931.

All the knowledge we possess of this condition is contained in the reports of Aviragnet, Armand-Delille and Marie, Dufourmentel, Reverchon and Worms Lasagna, Lemos, Lepine, Régnier and Lesbroc, and Barré, Draganesco and Lieou.

Six cases, in which two patients died, are reported; five of them are epitomized from Albertin's thesis. All six patients showed involvement of the pharynx, either dysesthesia or paralysis; in one case this condition was accompanied by paralysis of the larynx, in another, paralysis of the palate. Five of the cases represented the peripheral form of epidemic encephalitis. Bériel and Devic have shown that the encephalitic process can be predominantly localized in the nerves

and nerve roots, thus causing a special clinical form of polyneuritis. Histologic examination in one case showed lesions of the whole peripheral motor neuron, including the cell body, having precisely the diffuse inflammatory and nondestructive character of epidemic encephalitis. In support of this contention reference is made to a case of Economo's in which an encephalitic patient presented glossopharyngeal paralysis in the terminal stage of the disease. Histologic examination revealed recent lesions in the superior part of the nucleus ambiguus. From a clinical point of view, Dufourmentel's case is interesting: Two children of a family were attacked with cutaneous encephalitis. The first soon died; the second had a typical myoclonic form. There was an interval of several months between the two cases, but an important circumstance was that in the meantime a brother had velopharyngeal paralysis, accompanied by malaise and fever. Dufourmentel thought that the condition was an attenuated form of encephalitis, of an anteriosuperior poliomyelitic type, affecting the superior part of the nucleus ambiguus and comparable to the "peripheral" form of epidemic encephalitis. This form, though clinically peripheral, is undoubtedly central.

In agreement with Albertin, the authors believe that the velopharyngolaryngeal manifestations are especially the appanages of the peripheral form of epidemic encephalitis. These forms are less frequent, difficult to diagnose and generally curable. This explains the rarity of laryngologic sequelae and the poverty of our knowledge of the disturbances of the palate, pharynx and larynx occurring in the acute period of epidemic encephalitis.

DENNIS, Colorado Springs, Colo.

BENEDIKT'S SYNDROME WITH AUTOPSY. SOUQUES, CROUZON and BERTRAND, Rev. neurol. **2**:377 (Oct.) 1930.

In a patient, aged 50, there had been a syndrome of Benedikt from the age of about 4 years. There were paralysis of the right oculomotor nerve and spontaneous involuntary movements on the left, with paresis and contracture. The movements were very brusk, forceful and active, so that the patient had to keep her hand constantly controlled either behind her back or by the opposite hand. Movements were present also in the foot, and especially in the thigh. Voluntary movements were much limited. The face was less affected. It was impossible to examine the reflexes satisfactorily on account of the constant brusk movements, and it was also impossible to determine whether or not a Babinski sign was present. The patient complained of cramps in the limbs, but no objective disturbance of sensibility was noted. The development of the limbs had been arrested in large part. The right oculomotor nerve was not completely paralyzed, but there was no reaction to light, and the accommodation response could not be tested. The left eye was normal.

After death, a focus was found involving strictly the red nucleus on the right side and interrupting most of the fasciculi of the third nerve. The pyramidal tract was entirely uninvolved. The upper pole of the red nucleus was normal, and the corpus subthalamicum presented no lesions. The lateral part of the red nucleus had suffered less than the others. Wernicke's commissure was asymmetric, and the central tegmental fasciculus was scarcely visible. The reticular substance was markedly reduced. The left superior cerebellar peduncle was only about one-third as large as the right. The median fillet, however, was equivalent on the two sides. In the medulla there was hemiatrophy on the left side of the restiform body and of the reticular substance, and the periolivary stratum was reduced and pale. Nothing abnormal was observed in the spinal cord, and it was impossible to follow the course of the rubrospinal fasciculus.

The authors have collected and abstracted a number of cases of similar character, and compared the syndrome of Benedikt with that of Claude and others of the same nature.

FREEMAN, Washington, D. C.

Jugular Compression: an Adjunct in the Treatment of Syphilis of the Central Nervous System. Dudley C. Smith and J. A. Waddell, Arch. Dermat. & Syph. **24**:727 (Nov.) 1931.

Many chemical and biologic substances injected into the blood do not penetrate the hemato-encephalic barrier in concentration enough to exercise much direct effect on the central nervous system. To increase the effectiveness of intravenous antisyphilitic remedies, Smith and Waddell suggest applying jugular compression after the drug has been introduced into the blood stream. The procedure is contraindicated in hemorrhage, tumor and glaucoma. Compression is applied with an adjustable woven strap, which is wrapped around the neck; a metal button padded with leather is placed over each jugular vein, and as the strap is tightened these pads press on the veins. Engorgement of the facial veins and pulsations in the temporal artery indicate when sufficient pressure has been applied. The collar is tightened immediately after intravenous injection, and the pressure is continued for one half hour. The spinal fluid is then examined, and the arsenic content noted. In all, forty patients received injections of arsphenamine; twenty-two of them submitted to jugular compression, and the other eighteen served as controls. In the latter group, the arsenic content per hundred cubic centimeters of spinal fluid varied from 0.02 to 0.12 mg., with an average of 0.04, while in the group that received compression the range per hundred cubic centimeters was from 0.02 to 0.14, with an average of 0.061—an increase of 55 per cent. Each patient had a lumbar puncture thirty minutes after the intravenous injection.

This increase in arsenic concentration of the spinal fluid would suggest that jugular compression increased the amount of drug available for the central nervous system. However nine of the twenty-two patients who submitted to compression showed an arsenic concentration less than the average of the entire control group. In a discussion of this paper, Osborne of Buffalo pointed out that the chemical determination of the arsenic in the spinal fluid was not necessarily an index of the amount of the arsenic in the brain or cord parenchyma. He suggested that fever therapy with its accompanying vasodilatation might be a more effective adjuvant to arsenic treatment.

Davidson, Newark, N. J.

Progressive Pallidal Rigidity and Congenital Regressive Rigidity (Presentation of Two Clinical Cases). Paul Van Gehuchten, J. de neurol. et psychiat. **31**:560 (Sept.) 1931.

The author presents two cases. The first is described as a syndrome of progressive pallidal rigidity. The patient, a boy, aged 6 years, was born at term after a long, difficult labor. Development was more or less normal until the age of 2 years. He was able to stand at 1 year and gradually learned to walk, although with difficulty. At the age of 2 years there was a slow regression of voluntary movement; at the same time rigidity and choreo-athetosis developed. Objectively there were also dysarthria and spasmodic laughing. The author discusses the literature on the case; only a few similar cases have been reported. The second case is described as the syndrome of Mme. Cécile Vogt. In this instance the child was premature. At the age of 1 year extrapyramidal rigidity developed, complicated by choreo-athetosis, dysarthria and some dysphagia, but without pyramidal tract signs and without important intellectual deficit. The syndrome progressed to the point at which voluntary movement was practically impossible.

The author believes that these two conditions are comparable, the important difference being that the second case was congenital, whereas the first was not, the pallidal degeneration and rigidity appearing later. The etiology of the second type of case shows it to be due probably to dysgenesis, whereas the first type is usually associated with difficult labor and asphyxia and is possibly due to some

cerebral circulatory disturbance. The pallidal rigidity type of case is associated with a disturbance of the pallidum, spoken of as status dysmyelinisatus, while the other condition is associated with lesion of the striatum, known as status marmoratus. The author believes that by the study of cases such as these one may eventually arrive at the function of the paleostriatum and of the neostriatum. To the pallidal system is attributed the more important rôle in the regulation of postural tone. By some, the symptoms of choreo-athetosis and dyskinesia are interpreted as being evidence of striatal lesions, while others believe that such symptoms are evidence of involvement of the pallidum.

WAGGONER, Ann Arbor, Mich.

OCULAR COMPLICATIONS OF CHRONIC EPIDEMIC ENCEPHALITIS. THEODORE H. WHITTINGTON, Brit. M. J. **2**:981 (Nov. 28) 1931.

The author's observations are based on the notes of 174 cases of chronic epidemic encephalitis in children. The ocular symptoms of the acute stage are briefly reviewed, and attention is called to the report of the ministry of health, wherein it is stated that 78 per cent of the patients in a series of 1,152 had the external ocular muscles affected in some way or another. Ptosis was present in nearly 50 per cent, squint in 34 per cent, diplopia without obvious squint in 18 per cent and nystagmus in 18 per cent. The author emphasizes that the presence of papilledema or of optic neuritis is decidedly against a diagnosis of encephalitis.

In the chronic stage, ptosis was present in 6 per cent of the 174 cases studied. External strabismus was observed in 15 per cent. Only 2 cases showed vertical nystagmus, and in 1 there was paralysis of the internal rectus muscle. Very slight or absent pupillary reaction to accommodation was present in 47 (27 per cent) while direct light reflex was very slight or absent in 23. Six cases showed oculogyric crises. It is of great interest that abnormal pupils developed in some of the patients two or three years after the author noted them as normal. The oculogyric crises seemed to be peculiar to the parkinsonian form of the disease. The onset of the crises points to an activity of the disease, and would appear to indicate danger of psychotic symptoms. In a series of 136 cases which eventually had to be certified, 17 per cent showed oculogyric crises (McCowan and Cook). Other ocular symptoms, such as excessive blinking, fluttering of the eyelids and difficulty in moving the eyes in a vertical direction when told to do so, were considered characteristic of the overemotional state of the patients rather than of neurologic import.

The latter part of the paper has to do with the treatment of the paralysis of accommodation and the mydriatic pupil, which occurs in patients who are treated by large doses of belladonna derivatives and stramonium. A + 1.50 to 1.75 lens is indicated in some patients, while in others the condition is taken care of by physostigmine (eserine) and pilocarpine.

FERGUSON, Niagara Falls.

PHYSIOLOGIC ANALYSIS OF THE PROCESSES OF INHIBITION. K. AGADJANIAN, Encéphale **26**:690 (Nov.) 1931.

The author starts out with the basic views on inhibition, namely, that irritation of a nervous element does not always provoke an excitation, but may exert a negative influence. Quoting Sherrington's ideas that all excitation of certain muscular centers in the cortex is accompanied by depression of antagonistic muscular centers, he goes on to apply this idea to psychic functions. Thus, mental concentration is a positive and a negative activity simultaneously, an excitation of a dominant field of activity with a concomitant inhibition of other fields. In psychasthenia this attention or concentration is focused on the one "fixed idea." Certain limited functions are excited; all others are deprived of function. Echopraxia and echolalia are further instances of such inhibitory activity. Also, the

cataleptic state of hypnosis and catatonic states in general are characterized by extensive irradiations of inhibition. Going further, hallucinations may be explained by the lack of simultaneous activities of various parts of the cortex. In this connection he quotes Brugia to the effect that if the pathologic condition does not permit ideas to be reconverted into sensations it is because the greatest part of their force is taken up in the development of attention, volition, and other more "psychic" functions. The hallucination is "not to be regarded as an unusual association, but an unusual monopoly of an habitual association."

In the author's own work he employed cutaneous stimuli of monotonous alternating currents, inducing inhibitions of cortical points, and thus hallucinations were produced. If the irritating stimulus acts on the auditory perceptual centers visual hallucinations fade out. He believes that there are two types of neuroses, viewed from this angle, namely, irritative and inhibitive. In neurasthenia there exists predominance of excitation, and in hysteria, of inhibition. Epilepsy is also discussed from this point of view.

ANDERSON, Los Angeles.

ON THE SIGNIFICANCE OF HISTOLOGIC LESIONS OF THE SMALL INTESTINE AND OF THE LIVER IN AMENTIA SYNDROMES. U. DE GIACOMO, Riv. di pat. nerv. **38**:633 (Nov.-Dec.) 1931.

On the basis of Buscaino's conception that amentia and dementia praecox are due to abnormal amines in the gastro-intestinal tract and that these psychoses are enterogenic in origin, the author reviews the literature concerning lesions found in the gastro-intestinal mucosa and in the liver in cases of acute amentia. His purpose is to find a possible confirmation of Buscaino's contention that the abnormal amines are absorbed into the blood because of lesions in the gastro-intestinal tract. His material consists of seven cases in which he studied the stomach, large and small intestines and liver. He reports changes in the small intestine, the most constant of which is hyperplasia of the lymphoid elements and a tendency of the mucosa toward atrophy. In addition, hypersecretion of mucus and congestion of the mucosa and submucosa are often encountered. In the liver, de Giacomo found congestion with secondary atrophy of the parenchyma and fatty degeneration and often slight proliferation of the reticular connective tissue. He relates the lesions of the intestine with an irritative agent of toxic nature which may enter the blood and damage the liver. Both the intestinal walls and the hepatic tissue tend to react with lymphoid hyperplasia and proliferation of reticular fibers, but this protective reaction is insufficient and gradually the phenomena of atrophy and fatty degeneration occur in both, thus diminishing the protective barrier represented by these structures. The author thinks that the pathologic reaction in the intestine is comparable to the pathologic reaction found by other authors following the experimental injection of foreign proteins. In concluding, de Giacomo upholds Buscaino's conception of a toxic origin for both the essential and the symptomatic types of amentia.

FERRARO, New York.

FURTHER OBSERVATIONS ON THE GENOCUTIREACTION IN YOUNG SUBJECTS. P. JEDLOWSKI, Arch. gen. di neurol., psichiat. e psicoanal. **12**:41 (March 31) 1931.

Ceni's genocutireaction consists in an eruption of a certain type ("eruzione del tipo ponfoide"), usually surrounded with a pinkish halo, that follows the application to the scarified skin of a small quantity of an extract of sexual glands. This extract must not be confounded with the sexual hormone, as it is not specific and is ambivalent for both sexes. The reaction is negative in infancy; it gradually becomes positive and reaches its maximal intensity in the period of complete sexual development of the organism. In general disease conditions this reaction becomes negative only when such conditions are associated with a state of profound

debilitation (genetic cutaneous anergia as an expression of somatic anergia). In mental diseases the reaction is weak or absent, especially in depressive forms of psychoses (central genetic anergia), while in those with manic excitement the reaction is positive and may even be exaggerated. Age being an important factor in this reaction, the author selected for study 530 apparently healthy subjects between the ages of 19 and 21 years. His results were as follows: strongly positive reactions, 85.12 per cent (450); positive, 8.16 per cent (49); weak, 5.12 per cent (26), and negative 0.8 per cent (5). In 3 subjects of the last group the negative result was justified by the physical or psychic condition. In one subject a mental disease developed later. Thus, in only one subject did the negative test remain unexplained. A negative reaction is, therefore, exceptional in normal subjects, and if it is obtained gives reason to doubt the state of somatic or psychic health of the person concerned.

Yakovlev, Palmer, Mass.

The Pathologic Anatomy of Epidemic Encephalitis. Eugen Frey, Schweiz. Arch. f. Neurol. u. Psychiat. **27**:259, 1931.

Frey summarizes the results of the study of brains from persons suffering from epidemic encephalitis. Macroscopic changes were more frequent in both acute and chronic cases than is generally believed. Thromboses and areas of perivascular necrosis, furthermore, were found in some acute cases although changes of this type in cases of epidemic encephalitis have been denied. Vascular and perivascular changes were prominent in the entire group. These findings, as well as the frequency of changes in the ependyma and subependymal tissues, in the author's opinion furnish considerable support for von Monakow's view that the vessel walls, the perivascular glia, the ependyma and the choroid plexus constitute the first line of defense against the entrance of infective agents into the central nervous system *(haemo-encéphale barrière)*. Extensive cortical changes were noted in two brains. The experience of workers elsewhere relative to the activity of the glia cells, the regressive changes in the ganglion cells and the frequent involvement of the substantia nigra was confirmed. Changes in the thalamus and pallidum were less pronounced than might be inferred from a review of the literature. In a few cases, numerous foci of disease were found in the inferior olive and the dentate nucleus. Since parkinsonism has been entirely lacking in some cases in which the substantia nigra was badly damaged, and since many other parts of the brain are involved in epidemic encephalitis, Frey agrees with Bielschowsky that this and other phenomena of chronic encephalitis are attributable to a diffuse process rather than to lesions of particular centers.

Daniels, Rochester, Minn.

Remarks on Breech Presentation: Foetal Mortality and Injuries. G. F. Gibberd, Brit. M. J. **2**:369 (Aug. 29) 1931.

The author finds that the gross mortality rate for the infant in uncomplicated cases of breech presentation is about 30 per cent in primiparas and about 20 per cent in multiparas. "These figures," says the author, "dispel the old text-book inaccuracy that the fetal mortality associated with breech delivery is 3 per cent in multiparas and 10 per cent in primiparas." The most important cause (75 per cent) of fetal death is intracranial hemorrhage. The second and, in the author's opinion, only other important cause of fetal death is compression of the cord after the birth of the buttocks, producing asphyxia. A third cause, drowning from premature inspiration, is considered a "bogey."

The extent and frequency of intracranial injuries in children who live is difficult to estimate. Minor degrees of intracranial hemorrhage and tentorial

tears are not necessarily incompatible with life. That extensive lesions of the pyramidal tract are a result of injury to the rolandic area at birth are not considered likely. The work of Holland is cited as evidence; this investigator found that this area of the brain was the last and least affected by labor, and that a lesion extensive enough to cause damage to these parts was sufficient to cause death. The other most common neurologic complication is an Erb's paralysis, which should be treated by putting the arm in the "Israelite position," allowing active daily movements. If these directions are followed the result is usually good. Fracture of the humerus and the femur may occur, but severe damage to the viscera is uncommon.

FERGUSON, Niagara Falls, N. Y.

OCCUPATIONAL SPASMODIC RHINORRHOEA. E. WATSON-WILLIAMS and C. M. BRIST, Lancet **1**:1237 (Dec. 5) 1931.

Spasmodic rhinorrhea affords a good example of the curious group of diseases known as "allergic." In such cases often enough the coincidence of the onset with an illness, or with a change of residence or of occupation supplies a valuable clue to the etiology. But in others, although the periodicity or other circumstances point strongly to an occupational cause, the connection is obscure; the attacks pursue the patient from one occupation or residence to another. Again, there may be no material change in the occupation to account for the sudden appearance of attacks. In these cases the patient is prone to ascribe them to shock, overwork or nervous strain, recognizing clearly the "nervous" element in the causation.

In each of the three patients with rhinorrhea, under the authors' observation, the allergic response occurred because of occupation. One patient became afflicted when it became necessary to care for farm poultry; a second had attacks when handling opium or its derivatives; the third was affected after eating bacon. The attacks stopped in each case after the source of irritation was eliminated. Therefore, it is emphasized that before proceeding to dermal testing and densitization, or even to operation, it is worth while to spend time in a careful investigation of the circumstances and mode of life of the patient.

BECK, Buffalo.

MACROGENITOSOMIA PRAECOX ASSOCIATED WITH AN EPENDYMOGLIOMA OF THE MAMMILLARY REGION. G. HEUYER, J. LHERMITTE, DE MARTEL and C. VOGT, Rev. neurol. **2**:194 (Aug.) 1931.

A boy, aged 6 years, developed with abnormal rapidity and presented the physical appearance of a lad of 12. The sexual organs were especially well developed, with a good growth of hair. The patient suffered from headache, which was worse on quick movements of the head; he walked a little gingerly, but he had never had any vomiting or convulsive seizures. The reflexes were active, with plantar extension on the left. There was no somnolence, glycosuria or polyuria. The cranial nerves were normal. Mentally, he appeared to be backward, and a mental age of 3 years had been reported. The sella turcica was small; the convolutional markings were visible in the roentgenogram. The spinal fluid escaped under increased pressure but showed no abnormal elements. The epiphyseal region was explored without anything abnormal being found, and the child died two days after exploration.

Serial sections through the region of the tuber cinereum showed a cystic tumor, apparently originating in the right mammillary body, causing slight compression of the surrounding structures, with dilatation of the aqueduct of Sylvius, but no evident pressure on the optic nerve. The epiphysis was entirely normal.

FREEMAN, Washington, D. C.

THE TREATMENT OF POST-ENCEPHALITIC CHILDREN IN A HOSPITAL SCHOOL. EARL D. BOND and KENNETH E. APPEL, Am. J. Psychiat. **10**:815 (March) 1931.

The school for postencephalitic children was established at the Pennsylvania Hospital in 1926. The children admitted presented such behavior difficulties as lying, stealing, quarreling, enuresis, overaffectionateness, masturbation, swearing and cruelty. The nurse in charge of the school was psychiatrically trained, and could accept the irritating behavior of these children with equanimity and understanding. She took her meals with the children. Foster parents lived in intimate association with the children. In the school, recitation periods were short, but the children were kept busy almost all the time. A spirit of optimism was maintained, and the students were encouraged to feel that their difficulties were curable. Delinquencies were viewed unemotionally, and stress was laid on cooperation rather than on criticism, on understanding rather than on discipline. Twenty of the postencephalitic children were sent home, and seven showed a good social adjustment; of the forty-eight postencephalitic patients in the school, forty-five improved to a fair level. In addition to this improvement in the psychologic environment, the hospital by rest, diet and hygiene in general has promoted physical repair.

DAVIDSON, Newark, N. J.

THE FUNCTION OF THE INFERIOR OLIVE. L. J. J. MUSKENS, Rev. neurol. **2**:88 (July) 1931.

There seems to be little doubt that the olivary bodies have important functions with regard to the posture of animals. Damage to the median portion is associated with a tendency to fall backward, while damage to the ventrolateral portion produces forced movement forward. Interruption of the central tegmental fasciculus is characterized by a tendency to fall backward, while that of the ventral fasciculus is followed by a tendency to fall forward. In addition, one obtains vertical nystagmus but no paralysis of upward or downward movements of the eyes unless the lesion lies between the neostriatum and the oculomotor nucleus.

The comparative anatomy of the olivary bodies has been studied particularly by Muskens, and three types of mammals seem to stand out particularly. In the sloths, which have a tendency to curl up and hang downward, there is enormous development of the dorsal portion, the medial portion being well developed and the lateral scarcely at all. In the cetaceans there is "monstrous" development of the medial portion but very little of the lateral or dorsal, whereas in anthropoids and man there is enormous development of the lateral portion with very little of the medial or dorsal.

FREEMAN, Washington, D. C.

HEREDITY AND MENTAL DEFICIENCY. PAUL POPENOE, Ment. Hyg. **15**:570 (July) 1931.

The reversion of several geneticists to the old idea that feeblemindedness is a unit characteristic is lamented by Popenoe. The author acknowledges that in the lower levels of the intelligence scale there is a qualitative rather than a quantitative difference, and that an idiot differs in kind rather than in degree from a well rounded genius. But the bulk of scientific evidence points away from the unit character theory. Feeblemindedness itself is a largely undefinable concept, concerned as it is with social adjustment rather than biologic characteristics. Goddard's pioneer work, such as his study of the pedigree of the Kallikak family, is based on the uncertain foundation of subjective estimates by friends, workers and neighbors. Since to begin with there is no clearcut concept of feeblemindedness, all studies that divide rigidly the normal from the mentally defective are necessarily inaccurate. Popenoe hastens to remark that he does not doubt that feeblemindedness is inherited: what he questions is the way in which this transmission occurs. He concludes with an expression of approval of the program of the eugenists to limit the offspring of the mentally defective and encourage the breeding of the superior.

DAVIDSON, Newark, N. J.

THE NATURE AND LOCALIZATION OF A PARTICULAR MOTOR DISTURBANCE IN DEMENTIA PARALYTICA. E. ROSSI, Ann. di neurol. **44**:113 (July-Aug.) 1930.

Using the special staining method of Jahnel, the author has studied and described a specific hypertrophy and proliferation of the neuroglia of the inferior olivary nuclei, with the resultant atrophy of its neurons and fiber systems, in cases of dementia paralytica that had shown a particular motor disturbance. This perturbation of the motor system is manifested in the upper extremities by ataxia, leading to "apraxia"; and in the lower limbs by an incoordination varying from hesitancy and slowness of gait to total incapacity to walk.

Experimental lesions interrupting the olivocerebellar tracts in animals have given rise to an ataxia similar to that described. According to the author, a medullary (olivary) ataxia exists.

Study of the olivary nuclei and of the cerebellum in cases of dementia paralytica is strongly urged. Knowledge of the manifestations of disturbed function of the olivary nuclei is of extreme value, especially in cases in which these structures are attacked before the cortex. In such cases a diagnosis can be made early.

IMPASTATO, New York.

PERIODIC PSYCHOSIS AND DEMENTIA PRAECOX. HENRI CLAUDE and J. LÉVY-VALENSI, Encéphale **26**:377 (May) 1931.

This article is a long citation involving three cases in which the diagnosis between dementia praecox and manic-depressive psychosis presented the greatest difficulty. The authors come to blows with the habitual tendency to regard the schizophrenic process as necessarily permanent and progressive. They believe that the usual "precocity" of dementia praecox is based on a particular fragility of the cerebral cells, but are inclined to a conviction that there are varying degrees of this fragility, with cerebral resistance for a longer or shorter time, according to circumstances. Thus would the familial tendencies of schizophrenia be accounted for. Moreover, they are inclined to believe that all psychoses, even manic-depressive, produce some enfeeblement of the intelligence.

ANDERSON, Los Angeles.

GROUP TREATMENT OF THE PSYCHOSES BY THE PSYCHOLOGICAL EQUIVALENT OF THE REVIVAL. L. CODY MARSH, Ment. Hyg. **15**:328 (April) 1931.

On alternate days, Marsh gives classes for patients at a mental hospital who are willing to attend. Lectures are given, games are played, songs are sung, the testimonials of paroled patients are read, a catechism is recited and various group practices are carried out. Patients who are getting well are coached to tell their ward mates about their progress. During these community hours the patients seem to be happier; March considers that their energies are being extroverted. He is convinced, without presenting evidence for the view, that since insanity is largely the product of communal life it can be healed only by group activity. No claim is made that this technic cures or even shortens the duration of any mental illness, but it is thought that recovery is made easier and insight promoted by this method.

DAVIDSON, Newark, N. J.

Society Transactions

CHICAGO NEUROLOGICAL SOCIETY

Regular Monthly Meeting, Oct. 22, 1931

A. B. Yudelson, M.D., *President, Presiding*

Colloid Cyst of the Third Ventricle. Dr. Arthur Weil.

A linotype operator, aged 25, for three months had occasional headaches, varying in severity. He was able to work until five days before death. The headaches then became very severe; he vomited several times, saw double, and was not able to stand steadily or to walk straight. He had had ringing in both ears for several weeks; this became worse after the vomiting. When the patient came to the hospital he was extremely restless; he died in coma. There were the neurologic findings of bilateral retinal congestion, a horizontal nystagmus, with slow movements in either direction and large pupils which reacted sluggishly to light. The tendon and superficial reflexes were more lively on the right side; there were bilateral ankle clonus and Babinski sign. The spinal fluid contained 155 cells per cubic millimeter, 45 per cent of which were polymorphonuclear. The colloidal gold test gave a curve of the meningeal type.

At autopsy, a healing mitral endocarditis and bilateral fibrous pleurisy were found. In the third ventricle there was a small cyst of the tela choroidea, measuring approximately 1 cm. in diameter; it was attached to the upper part of the posterior wall. The lateral ventricles were dilated. Microscopically, the wall of the cyst showed proliferation of the lining ependymal cells and marked infiltration with small round cells, most of which had fragmented nuclei. The center of the cyst consisted of two concentric layers; the outer zone of the inner layer was a homogeneous mass; in the center there was a dense mass of cellular débris. The outer layer contained numerous cells like those found in the wall of the cyst and large phagocytic cells. The surrounding choroid plexus did not present any inflammatory reaction.

At the point where the wall of the cyst was attached to the fornix, a thick layer of connective tissue had been formed; it was surrounded by foci of perivascular round cell infiltration in the adjacent brain tissue. In the tuber cinereum, in different regions of the cerebral cortex and in the upper cervical region of the spinal cord other foci of inflammation were present. The meninges did not show inflammatory reactions. The case is presented to point out the spreading of the encephalitis to the cyst wall at the point where the tela choroidea is attached to the fornix. Dr. H. R. Fishback furnished me with the material.

DISCUSSION

Dr. Percival Bailey: There seems to be an epidemic of these cysts at present in Chicago. At the next meeting of the Chicago Pathological Society, an exactly similar cyst of the third ventricle will be presented by a member of the department of pathology at the University of Chicago. This makes three that have occurred here in a year. The explanation that Dr. Weil gives is ingenious, but it does not explain why all these cysts occur in exactly the same place, between the foramina of Monro. Sjövall explained this when he said that these cysts arise from the anlage of the paraphysis. In man it occurs in only very young embryos; the structure disappears when the embryo is 10.5 mm. long This hypothesis explains more of the known facts concerning these cysts than any other.

Some Postural Reflexes in Man. Dr. Joseph Lehan (by invitation).

This article will be published in full in a later issue of the Archives.

Regular Meeting, Dec. 17, 1931

A. B. Yudelson, M.D., *President, Presiding*

Multiple Benign Ganglioneuromas. Dr. Arthur Weil and Dr. Hale Haven.

In March, 1931, a married white woman, aged 23, was admitted to the Passavant Memorial Hospital to the service of Dr. A. H. Curtis. During the one and a half years prior to admission she had lost 25 pounds (11.3 Kg.), had felt fatigued and lacked normal endurance and had noticed bilateral pressure in the inguinal region somewhat similar to menstrual pain.

At the age of 4 years, she had had a lump removed from the left side of the neck, which was reported as being a fatty nerve tumor. One month after its removal it reappeared and was present until four weeks previous to her admission to Passavant Hospital, when it was removed by Dr. de Takats at Wesley Memorial Hospital. The report of the operation recorded that below the deep cervical fascia on the left side of the neck a large, firm, lobulated mass the size of a child's fist was exposed. It lay on the large vessels and extended below the clavicle to the pleura and upward as far as the fourth cervical transverse process. In removal there was no bleeding, and the surrounding tissues were separated from the mass in a good line of cleavage.

General examination revealed the following pertinent facts: There were two well healed scars, one old and one new, in the left supraclavicular region. The thyroid was palpably enlarged, but the basal metabolic rate was —19. An irritative cough was present, but no clinical signs were found in the chest. A mass was palpable in the lower right quadrant of the abdomen. This mass was not tender. Vaginal examination revealed a freely movable, small uterus, displaced to the left, and an ill defined, relatively fixed tumor-like mass, evidently retroperitoneal, in the right pelvis, which faded away as it entered the midabdomen. Roentgenograms of the chest failed to reveal evidences of mediastinal tumor masses. The impression was that the mass was probably a retroperitoneal malignant growth of unknown origin, with the qualification that there was a remote possibility of tuberculosis.

On exploration of the abdomen the following conditions were noted: There was no free fluid in the abdominal cavity. The liver was smooth and the gallbladder normal. The left kidney was about one-third smaller than normal. The left suprarenal was from three to four times the normal size; it was relatively firm but freely movable, and cystic areas were felt in it. The right kidney and suprarenal were essentially normal to palpation. The uterus was of normal size, upright and movable. The tubes and ovaries were normal. To the right of the spine was a chain of retroperitoneal tumor masses extending from the region of the right kidney down over the pelvic brim into the region of the broad ligament; it consisted of a conglomerate mass of firm glandlike tumors ranging in size from that of a walnut to that of a fist. The tumor mass was too firmly fixed and too extensively bound up with the great pelvic vessels to permit of surgical removal. A fairly large portion was removed for histologic study. While the gross impression of the surgeon at the time was that the mass was malignant, he remarked, "It is significant that the tumor mass removed from the neck by Dr. de Takats a few weeks ago was a ganglioneuroma."

Through the courtesy of Drs. Curtis and de Takats it was our privilege to study both the specimen from the neck and the one from the abdomen. Peculiarly, it was noted that one description would serve for the two specimens without qualification.

Grossly, the tissue removed was grayish pink, homogeneous, relatively firm and almost gummatous.

Microscopically, the tissue had the characteristic appearance of a so-called true ganglioneuroma. In this case there was a rather coarse reticular arrangement of fibrous tissue, in the interstices of which were strands of unmedullated nerve

fibers with sheaths, and intermingled with these fibers were ganglion cells, mostly with one nucleus, though occasionally a cell had two nuclei.

In the literature, beginning with the first authentic case of ganglioneuroma reported by Loretz in 1870, there are now reports of about ninety cases of so-called ganglioneuroma. Most of the cases were of single tumors; in two cases, one reported by Knauss, in 1898, and the other by Kreidel and Benecke, in 1903, there were multiple subcutaneous tumors; the few remaining multiple tumors all showed malignant neuroblastomatous characteristics in microscopic section.

As far as we can tell from a thorough review of the literature, this is the first case on record of multiple true benign ganglioneuromas occurring simultaneously in the cervical and abdominal sympathetic chains.

NEUROLOGIC COMPLICATIONS OF POLYCYTHEMIA VERA, WITH PRESENTATION OF A CASE. DR. LEROY H. SLOAN (by invitation).

In the neurologic service of Dr. Hall and Dr. Favill was a patient with polycythemia vera who also showed interesting neurologic conditions. Shortly thereafter, two patients with polycythemia were seen in private practice, in one the disease was of the Vaquez type and in the other probably of the same type; both complained of symptoms of neurologic interest. During the last few years, much interest has been taken in diseases of the blood and the blood-forming organs, largely as a result of the work of Minot and Murphy, Robsheit-Robbins and Whipple on anemia in general and primary anemia in particular. Polycythemia is the opposite of anemia among diseases of the blood. It is a condition in which there is overabundance of red cells with an added amount of hemoglobin. It stands in the same relation to the general condition of erythrocytosis as leukemia does to leukocytosis.

Polycythemia occurs in two forms:

1. Relative polycythemia produced by diarrhea, profuse perspiration, dehydration, exercise, massage, alteration in blood pressure, chlorine, chlorpicrin, phosgene, mustard gas, asphyxia, epinephrine and emotion. (The red blood cell count may be as high as 15,000,000 [Ferrari].)

2. Absolute polycythemia, of which there are two types: (*a*) Ayerza's disease; pulmonary stenosis; mitral stenosis; pulmonary emphysema. The altitude at which the disease occurs according to Paul Bert is that of the home of Peruvian sheep; according to Douglas, Haldane, Henderson and Schneider that of Pike's peak. This is erythrocytosis. (*b*) Polycythemia rubra vera (Vaquez and Osler); also called myelopathic polycythemia, erythremia megalosplenia and splenomegalic polycythemia with chronic cyanosis. (Vaquez, in 1892, probably published the first observations. Rendu and Widal have been given priority by some. Saundby and Russell first named the disease as an entity. Purves Stewart's case was the first one recognized in London. Osler, in 1903, brought the condition to the attention of English-speaking physicians.)

Etiology.—1. The condition is sometimes considered as of familial occurrence (Engelking; Nichanin; Doll and Rotschild).

2. Cases have been reported in which the condition resulted in leukemia, pernicious anemia, secondary anemia or eosinophilia.

3. Leukemia and anemia that developed into polycythemia have been reported.

4. The essential factor is a stimulation of the hematopoietic tissue of the bone marrow.

Pathology.—The disease is characterized by overfilled blood vessels, thrombosis, peripheral arteriosclerosis, splenic enlargement, hyperplasia of the bone marrow and other erythropoietic tissues and leukopoietic areas, cerebral softening, thrombosis and hemorrhage.

Neurologic Symptomatology.—There is a preponderance of nervous manifestations. The distinction between the lesions of pernicious anemia and those of poly-

cythemia vera rubra is the presence of cerebral vascular symptoms in the former and of cord symptoms in the latter condition.

Vaquez reported vertigo, buzzing and whistling in one ear, staggering and a feeling of floating. Cuffer and Sollier reported vertigo. Osler reported headache and vertigo. Cabot, in one patient, reported sudden loss of consciousness, thick speech, collapse, spontaneous movements of the feet and legs, irritation, weakness of the left arm and leg, and middle meningeal hemorrhage; in a second patient, he reported dizziness and vertigo. Saundby and Russell reported dulness, poor memory, thick speech and congestion of the brain. Weber reported angina cruris, tabes dorsalis, uncontrollable impulses, insanity and somnolence. Guenther reported polycythemia (not of the Vaquez type) with narcolepsy. Hutchinson and Miller reported convulsions, twitching of the face and mouth, vomiting, hematemesis, headache, loss of sight, dulness and stupidity and somnolence, with soft suprarenals, enlarged spleen, edema of the pia-arachnoid, injection of the meningeal vessels and yellow, dry softening of the occipital lobe and the tip of the temporosphenoidal lobe, the lateral lobe of the cerebellum, the left lenticular nucleus and the right optic thalamus.

Morris, in 1910, reported epileptiform convulsions, headache, dropping of articles, petit mal and automatism. Goldstein found focal softening in the brain, but the cerebral vessels were not diseased. Parkinson, in 1912, reported cerebral hemorrhage and cerebral thrombosis. Lucas, in 1912, summarized one hundred and seventy-nine cases and reported choked disks, cerebral hemorrhages, in three instances tinnitus, apprehension, excitability, irritability, delirium, disturbed mentality, insomnia, insanity, absence of knee jerks, muscular atrophy, numbness, choreiform attacks, hemiplegia, aphasia, disturbed speech and loss of consciousness. Of twenty-three cases four showed softening of the brain and cord. Ward, in 1914, reported giddiness, paroxysmal attacks of dyspnea, paroxysmal vertigo which was worse when the patient was lying down, and attacks during which he became oblivious of his surroundings and lost sight of figures but was not unconscious.

Christian, in 1917, reported ten cases, with neurologic disturbances as follows: (1) headache, transient blindness and blurring of vision; (2) none; (3) fainting, nervousness, insomnia and disturbance of vision; (4) headache, scintillating scotomas, tingling in the left arm and leg, wristdrop, paralysis of the left arm, astereognosis, hemihypesthesia, conjugate deviation to the left, edema and hyperemia of the disk (autopsy showed bilateral thrombi of the cerebral arteries); (5) toe drop, dizziness, poor memory and paralysis of the left leg (autopsy showed thrombosis of the cerebral arteries); (6) headache, decreasing vision, diplopia, blurring, staggering to the right and left hemiparesis (a decompression was done); softening with cerebrovascular sclerosis was found at necropsy; (7) frontal headache, difficulties in speech, blurring of vision, paralysis of the right arm and leg and palsy of the left external rectus; (8) headache, numbness and attacks of weakness.

Bassoe reported severe pain in the right arm for five years, brachial neuralgia, arthralgia and drum-stick terminal phalanges. Pollock, in 1924, reported the case of a woman, aged 38, with headache when recumbent, attacks of dyspnea, headache accentuated by each heart beat, unintelligible speech, chorea and engorged retinal veins. Owen, in 1923, reported numbness of the right arm and leg, tingling, "going to sleep," difficulty in articulation and tingling around the mouth; the patient had had migraine between the ages of 19 and 35. Brown and Giffin, in 1923, studied the common sensations in these patients and found paresthesias of the feet. Winther reported multiple foci of hemorrhage in the brain; both hemorrhages and softening were found; there were: mental deterioration, apraxia, aphasia, weakness of the right side and softening of the left parietal lobe, necrotic foci in the white matter and glial reaction, and the capillaries and small blood vessels were greatly distended with stasis and thrombosis. LeDoux, in 1924, reported the case of a patient with sudden dizziness, who fell in the street without loss of consciousness and who had vertigo even when lying down, and left hemiplegia; some months later, another attack occurred with right hemiplegia. Mendel

reported choreic manifestations, with apraxia and paralysis. Zadek, in 1927, noted easy hemorrhage in these patients; there was rapidity of coagulation; the vessels were overfilled; the vessel walls were intact and not diseased; there were choked disk, periodic darkening of the field of vision, excitement, exhaustion, depression, hallucinations of smell, loss of memory and compulsory ideas of obscene sexual character. Dubowy, in 1927, reported severe headache; buzzing in the ears; paralysis of the right limbs; disturbance of speech; these cleared readily and disappeared with roentgenotherapy.

Brower, in 1927, reported the case of a patient, aged 57, who had had a stroke the year before, with disturbance in speech and paralysis in the right arm and leg; another attack occurred on the same side; the hemoglobin measured 136 per cent and the red blood cells numbered 8,900,000. Autopsy on the brain revealed hyperemia, but no well marked thrombosis. Brower reported the case of another patient who entered the hospital with the same disease with psychic disturbances. Doll and Rotschild reported Huntington's chorea in association with the disease. Brockbank, in 1929, reported frequent symptoms referable to the nervous system but not localizable. He found headache in thirty-three of fifty-six cases, slight mental impairment in eleven, paresthesia in eleven and general pruritus in four. In twelve cases with a complete neurologic examination, three patients had had cerebrovascular accidents; five probably had, and four certainly had defects in the visual fields. In the first four cases, a left homonymous hemianopia occurred in two, right partial hemiplegia in one and inferior altitudinal anopsia in one. The sixth patient showed an unaccountable nystagmus; the seventh showed no neurologic symptoms, and the eighth showed a complex resembling Wilson's disease.

Oppenheimer, in 1929, reported that he had performed an operation for brain tumor in 1926. Degeneration of the cortex was found. Before operation, examination of the blood revealed 6,000,000 red cells and hemoglobin 90 per cent. Thirteen months after operation, there was typical polycythemia vera. At autopsy a medulloblastoma was found. Cobb and Hubbard cited the influence of venous stasis in producing hemorrhages into the parenchyma of the brain. Tizianello, in 1930, reported the case of a patient, aged 21, who had spontaneous subarachnoid hemorrhage.

In anemia, the cord symptoms stand out. In leukemia, because of infiltration with leukemic deposits, there may be changes in the brain, cranial nerves, spinal nerves and cord as a result of compression. In polycythemia the lesion is essentially and distinctly vascular, and the preponderance of symptoms and signs is due to lesions in the brain.

REPORT OF CASES

Case 1.—W. S., aged 57, referred by Dr. Cleveland J. White, had had pruritus for seven years. When he was a boy, his nose would bleed when he was shaken. He had been seen by dermatologists, internists and neurologists. The following diagnoses were made: neurasthenia, psychasthenia, obsession neurosis, anxiety state, possible early manic-depressive psychosis and inferiority complex.

Examination of the blood revealed: hemoglobin, 118 per cent; red cells, 6,064,000, and white cells, 12,600, of which 82 per cent were polymorphonuclear neutrophils. The spleen was easily palpable. Cyanosis with suffusion was present on the face and body.

A gastric hemorrhage occurred and the patient felt better. He was placed on a milk diet and became worse. The hemoglobin was 110 per cent after the severe hemorrhage; the red cells numbered 6,200,000, and the white cells 34,600. Then he had another hemorrhage and became better. At the time of this report he is being treated with phenylhydrazine hydrochloride.

Case 2.—R. I., a lawyer, aged 43, had apprehension, a feeling of inferiority, lack of confidence in himself, fear of breaking down and a feeling that his fundamental training was not sufficient; recently he had experienced a lack of ability to carry on a logical train of thought, with palpitation of the heart, inward

nervousness and consciousness of the heart. The basal metabolic rate was —19. The hemoglobin was 100 per cent (Sahli) and 115 per cent (Hellige); the red blood cells numbered 5,640,000 and the white blood cells, 6,800. The spleen was palpable.

CASE 3.—M. M., a man, aged 40, entered St. Luke's Hospital in the service of Dr. Samuel Plummer and was seen through the courtesy of Dr. George Hall and Dr. John Favill to whose service he was transferred. While carrying on his work as a vender of food at the Stadium he suddenly noticed that he could not speak. He tried to make others about him understand, but could not, waved his arms, became excited and suddenly had a spell in which he fell; he was picked up and then walked to an automobile, in which he was taken to the hospital. Attendants stated that he was able to help in taking off his clothes. However, the patient remembers nothing after falling at the Stadium until he woke up in the ward at the hospital.

From his wife it was learned that for some time the patient had had severe headaches, with dizziness and some vomiting. In the last year he had had at least three rather peculiar attacks with much vomiting, headache, dizziness and paroxysmal dyspnea. She attributed all of the troubles to his having been gassed in the war.

While a patient in the hospital, he showed the following: marked headache; nausea; vomiting; pronounced rigidity of the neck in all directions; a positive Brudzinski sign; a positive Kernig sign; increased deep reflexes on the right side; paralysis of the right side of the face of central type; paralysis of the right arm, and aphasia, chiefly of a motor type. Further examination showed: diffuse, pronounced suffused cyanosis, with pronounced gingivitis; a reddened soft palate; fiery red mucosal surfaces of the mouth; very red tongue; dilated tortuous veins of the retina; cyanosis of the lips; normal blood pressure, and a definitely palpable spleen. The hemoglobin had been recorded as + 100 per cent. On careful check it was found that the hemoglobin was actually 157 per cent on one occasion, 128 per cent (Sahli) on another occasion and 130 per cent (Sahli) on another. The red blood cell count was always over 6,000,000, and at times was recorded as over 7,000,000. The patient showed, therefore, all of the characteristic signs of polycythemia vera, and later studies confirmed this impression in all details. Because of the severe rigidity of the neck, together with nausea, vomiting, dilatation of the retinal veins and paralysis of the right lower part of the face and the right arm, spinal punctures were done. The fluid was at all times under increased pressure, and showed a marked amount of blood in the first puncture, which was evenly distributed through the tube. The second, third and fourth punctures showed the same type of bloody fluid. The fifth puncture showed yellow fluid, and the yellow color persisted during the patient's stay of eight weeks in the hospital. The patient was given phenylhydrazine hydrochloride 1½ grains (0.1 Gm.) three times daily. In about ten days there began a progressive reduction in the number of red blood cells and in the percentage of hemoglobin. The white blood cell count fell for a time and then rose, so that when the hemoglobin had reached 60 per cent and the red blood cells were just above 3,000,000, the white count had reached a peak of over 20,000, mainly polymorphonuclears. With the development of the anemia as a result of treatment the spleen enlarged until it was of maximum size when the red count and hemoglobin were at the low point. Coincident with the enlargement of the spleen, the indirect van den Bergh reaction became strongly positive. The patient improved and was able to return to work, though he still showed a definite aphasia.

On November 20, to determine whether blood was still present in the spinal fluid or whether the coloration of the fluid was still present, another puncture was done, with the removal of 2 cc. of clear fluid. Twenty-four hours later, the patient showed all of the characteristics of severe meningitis. Spinal puncture was done, and a cloudy fluid containing 4,500 cells, almost entirely polymorphonuclears, was obtained. On the following day another puncture revealed a fluid with 6,000 cells. In the third day the spinal fluid showed 3,200 cells. Two days

later, the cell count had fallen to 171. A doubtful gram-negative diplobacillus was obtained from the first fluid cultures. Succeeding fluid cultures were negative. At the time of this admission to the hospital the patient had hemoglobin of 170 per cent and over 7,900,000 red blood cells. The diagnosis of a spontaneous subarachnoid hemorrhage in a patient with polycythemia vera was made. Subsequent to discharge from the hospital, because of the original attack, sterile meningitis of an unusual type developed, from which a rapid recovery was made.

DISCUSSION

Dr. Peter Bassoe: Two weeks ago, in consultation with Dr. H. M. Ripley of Kenosha, I saw a case of polycythemia in an advanced stage. A business man, aged 75, for ten days had had some stiffness of the neck and pain in the right side of the face. The diagnosis of polycythemia was made as long as twelve years before. At that time the spleen was decidedly enlarged. In 1922, the red blood cell count was 7,080,000, the white cell count was 15,400 and hemoglobin was 100 per cent. The highest red cell count was in 1923, namely, 9,500,000. In 1930, a change in the blood began to take place. Dr. Sloan spoke of the relation of this condition to leukemia, and the same transformation occurred in this case as occurs in leukemia. By June, 1930, the red cells had decreased to 2,090,000, while the white cells were 113,500, with 24 per cent myelocytes. On November 27 the hemoglobin was 51 per cent, red cells numbered 2,960,000 and white cells 95,700 with 2.5 per cent myelocytes.

In 1922, there was an attack of paresthesia on the left side, and in 1927 there was a questionable left hemiparesis, but both these conditions cleared.

When I saw him the patient had the picture of meningism. There was a slightly positive Kernig sign. He had bilateral cataracts so that I could not see the eyegrounds. I thought that the case essentially was one of polycythemia with a change in the blood picture in that stimulation of the formation of leukocytes had taken place. By consulting the last two years' volumes of the *Quarterly Cumulative Index Medicus* I found six or eight articles dealing with the relationship of polycythemia and leukemia. I thought that the meningism was due to hemorrhage or to a tissue infiltration in the meninges such as is observed in leukemia and that in either case something could be learned by the making of a spinal puncture. The fluid was colorless but slightly cloudy and under pressure. I took one tube with me and left the other with Dr. Ripley, who was going directly to the laboratory. I left my tube in the icebox until the next day and then found a film just as in poliomyelitis. The sugar was 46.5 mg. and the protein 283 mg. per hundred cubic centimeters. The globulin test was positive and the Lange curve showed a slight reaction a little to the right. When the fluid was examined in the laboratory the next day the cell count was 1,360, but that figure is not reliable. There were 30 per cent polymorphonuclears and 70 per cent mononuclears. Up to the time of this report cultures have been negative. The patient had some relief from his headache on the day after the puncture. On the next day he had headache again and three days later he had aphasia and became more drowsy. He had been very weak for several months. The temperature was normal when I saw him, and the maximum had been only 99.4 F. The blood pressure was 120.

The last information I received was on Dec. 12, 1932. The patient had remained in a semiconscious condition, with the temperature not higher than 100 F. Petechiae had developed, and he still had stiffness of the neck and an irregular pulse.

The interesting thing is that in this patient, who has reached the age of 75, with polycythemia that was severe enough for the spleen to be enlarged twelve years ago, the blood picture has changed entirely to that of leukemia.

Note.—The patient gradually became rigid and comatose and died on December 17. Necropsy was not performed.

Dr. R. P. MacKay: I wish to make a suggestion that may assist in explaining the high white cell count in the spinal fluid following the convulsion in case

3 reported by Dr. Sloan. Several observers have described a high leukocyte count in the spinal fluid produced by irritation of the meninges or ependyma by tumors or thrombosis with infarction. In one case, reported recently by Parker (Parker, H. L.: Tumor of Brain, Associated with Diffuse Softening and Turbid Cerebrospinal Fluid; Report of Case, J. Neurol. & Psychopath. **10**:1 [July] 1929), a patient rapidly became hemiplegic with acute meningism and exhibited a purulent, but sterile, spinal fluid. At necropsy a small tumor was found in the tip of the temporal lobe, with thrombosis and infarction in the neighboring region. No other explanation for the purulent spinal fluid could be found. I wish to suggest that what happened in Dr. Sloan's case was the formation of a thrombus, with softening involving the meninges or ependyma and resulting intense leukocytosis in the spinal fluid.

A Study of Extramural Epileptic Patients. Dr. Harry A. Paskind.

This paper appeared in the August, 1932, issue of the Archives, p. 370.

Putrid Abscess of the Brain: Its Pathogenesis. Dr. Isadore Pilot (by invitation).

My excuse for bringing this type of abscess of the brain to the attention of this society is the result of the studies, largely bacteriologic, that my colleagues and I have made with reference to certain anaerobic organisms, Bacillus fusiformis and the associated spirochetes.

Our first interest in the putrid abscesses of the brain developed when we found that in a series of thirty-five cases of diseases of the chest, which included cases of bronchiectasis, pulmonary abscess and gangrene, there were two in which the primary cause of death was the complicating brain abscess. Since then we have been on the lookout for such cases, and as the result of several years' observation, I shall present some of the features peculiar to these lesions in the brain.

First, most of these putrid abscesses, as has been pointed out by other observers, are pulmonary in origin. However, they are not entirely so. In a series of cases in the last three years at Cook County Hospital, in 1931, for example, there were six brain abscesses; one was pulmonary in origin and putrid, four nonputrid abscesses were otitic in origin, and one nonputrid abscess was associated with multiple abscesses of the lung. In 1930, of two cases of brain abscess one was of undetermined origin and one followed sphenoiditis. In 1929, there were two cases of pulmonary origin, both putrid, and two of otitic origin. It would seem that between those of otitic origin and those of pulmonary origin, there is a predominance of abscess in otitis media. Putrid abscesses are practically all of pulmonary origin. With the exception of the one associated with multiple abscesses in the lung, all the abscesses of pulmonary origin were putrid; of those of otitic origin only one was putrid.

In my personal postmortem experience I have observed in the last five years three abscesses of the brain: One was putrid, of otitic origin, in the temporosphenoidal lobe; one, nonputrid, complicating otitis media, and the last, nonputrid, complicating osteomyelitis.

Of the peculiarities of these lesions, aside from the frequency of the pulmonary source, I wish to emphasize the bacteriologic phase. These putrid abscesses are always due to mixed bacteria. In the experience of my associates and me, anaerobic organisms are always found in association with the streptococcus. Dr. Dick has reported an abscess with a pure culture of fusiform bacillus, but that is contrary to our experience. It seems to be necessary that there be a symbiosis of the anaerobic organisms with pyogens. Another observation is that one can always demonstrate large numbers of bacteria in the abscess wall. This differs from the nonputrid abscesses. Another peculiarity observed in our studies is that the anaerobes in this connection were largely fusiform bacilli without spirochetes. We were struck with the absence of spirochetes; although in the lesion of the lung

there may be enormous numbers of bacilli and spirochetes, in the brain we found bacilli and no spirochetes.

The symptoms do not appear to be acute; at times the condition may be asymptomatic for months and become obvious only when terminal meningitis sets in. In microscopic sections the abscess reveals a chronic inflammatory reaction. There are distinct walls about it in the form of well defined capsules. The complication is an acute meningitis, which is due not to the anaerobes but to the associated streptococcus.

There are a few points I wish to bring out with reference to a lesion that develops from organisms that are often found about the teeth and around the tonsils, where they may be normal or in lesions. These locations are often foci of infection, but no one has demonstrated that abscess of the brain develops from infected tonsils and teeth, as one is prone to believe in relation to other conditions. In brain abscess it seems necessary to have an intermediate advanced lesion of some type in the lungs, the sinuses or the ears, due to the same organism. These bacteria develop in large numbers, particularly in the lung, where they may have access to the larger vessels, with the formation of thrombi, and then be carried by the blood stream to the brain.

Another peculiarity is that, with enormous numbers of bacteria in pulmonary lesions, when the patient comes to necropsy metastatic abscess are found only in the brain and there is no sign of abscesses elsewhere. The brain seems to be peculiarly susceptible to the development of these organisms, whereas the liver, spleen, kidneys and skin seem to be immune. That is not true, for example, of pure staphylococcus or streptococcus infections. When there is sepsis from an ordinary lesion with these organisms one will usually find multiple abscesses in many viscera as well as in the brain. The brain seems to be a culture medium especially for the development of mixtures of the anaerobic organisms and pyogenic cocci.

In summarizing, I may add that these putrid abscesses of the brain may be multiple. The second and the last patient in the group that I showed had multiple abscesses. The multiple abscesses are almost always in the cerebrum rather than in the cerebellum. In the cerebellum abscesses are more likely to be single and of otitic origin.

The bacteriologic characteristic is the association of the anaerobic fusiform bacilli with streptococci. The tendency toward a chronic type of abscess is marked. The terminal picture is more likely to be that of meningitis. The lesion is always progressive, and while the abscess has a reaction capsule, I do not believe that it will ever heal spontaneously, nor do I know of any evidence of healed abscess in the brain complicating pulmonary lesions.

Regular Monthly Meeting, Jan. 21, 1932

PERCIVAL BAILEY, M.D., *Vice President, in the Chair*

LAMINECTOMY WITH POSTERIOR ROOT SECTION FOR ANGINA PECTORIS. DRS. LOYAL DAVIS and LEWIS J. POLLOCK.

The literature on the relief of pain in angina pectoris is voluminous, and the operations that have been performed on the sympathetic nervous system have been many. How to block the pain of angina pectoris in the most efficient manner is still an open question. It is known that the pain is referred from the heart to the upper five segments of the dorsal cord, and that its chief conduction path is via the inferior cardiac nerves and the stellate ganglion to the upper thoracic sympathetic chain; further, that a part of the painful impulses descends along the lower cervical sympathetic trunk, from the middle cardiac nerve, and a third pathway crosses directly from the heart to the upper dorsal ganglia. From these

ganglia the pain fibers enter the dorsal nerve roots by the white rami communicantes. As pointed out by Mackenzie, Langley and Swetlow, no operation limited to the cervical sympathetic trunk can interrupt all of these pathways.

However, three surgical procedures are theoretically capable of blocking all the cardiac pathways of pain to the spinal cord: (1) removal of the stellate ganglion with the upper five thoracic sympathetic ganglia, (2) cutting or blocking the corresponding rami communicantes and (3) cutting the corresponding posterior spinal nerve roots. The last procedure is the only method that preserves the cardiac accelerator fibers. Mandl in Vienna and White of Boston have made paravertebral injections of procaine hydrochloride and alcohol in attempts to block the rami communicantes. We also have employed this method with results no more satisfactory than those reported by White. There is no available proof as yet that the heart is not injured by the blocking of its accelerator fibers in such a procedure. Further, it is not known definitely whether the relief of pain results from the blocking of the motor impulses or from the interruption of the sensory afferent paths. Since the two pathways are separated only at their point of entrance into the spinal cord, considerable information could be obtained by cutting the posterior roots of the appropriate thoracic segments.

The patient we are presenting is a man, aged 50, who had suffered precordial pain for ten years. It was stabbing, began at the sternum and radiated to one or both arms, and then down the ulnar sides of both arms, extending into the little finger of the left hand. It was present on exertion or at rest. Dyspnea was a marked symptom.

The Wassermann reaction of the blood was negative. The transverse diameter of the chest is 34.4 cm.; the left side of the heart, 9.16 cm.; the right side of the heart, 5.3 cm. An electrocardiogram showed a sinus mechanism; the rate was 94, and the conduction time normal. The Pz was inverted, and there was a marked left ventricular preponderance. The blood pressure was 150 systolic and 90 diastolic. In spite of nitroglycerin, the pain became worse. The heart remained normal in size, but the patient could not sleep on his back because of pain.

On Dec. 11, 1931, a laminectomy was performed. The first six thoracic posterior roots were sectioned bilaterally. The relief of pain was immediate, and the patient is now able to sleep in any position. He has run up and down a flight of stairs without pain, though with dyspnea. The electrocardiogram has not changed.

As far as we are aware, this is the first recorded case of the relief of pain in angina pectoris by posterior root section.

Chordotomy. Dr. Eric Oldberg (by invitation).

Operations on the central nervous system for the relief of pain were first proposed about half a century ago. The first operation proposed, by Dana, in 1886, was that of section of the posterior root for the relief of severe neuritic pains. Bennett was the first to accept Dana's suggestion and to perform posterior rhizotomy, in 1888. The operation gradually gained favor, and, in 1900, Mingazzini proposed it for the relief of pain in tabetic gastric crises. The operation was performed first by Küttner, in 1908, at Förster's suggestion. It was, however, destined to go through a rise and fall of esteem, and in 1917 Frazier reported that section of the posterior root for gastric crises had a mortality of 15.7 per cent and that it produced only 19 per cent of cures. Others also reported unfavorably on the operation, and Leriche said that he had never seen a cure of gastric crises; Elsberg said that he had never seen complete and permanent relief from the pain of malignancy.

The operation of partial section of the cord was preceded by considerable work in the localization of the fibers transmitting pain and temperature in the cord. In 1879, Gowers first suggested that pain and temperature passed up the cord in the same tract, i. e., the tract of Gowers, and in 1893, van Gehuchten stated this to be a fact. Spiller, in 1904, proved these hypotheses to be correct;

he had had a case of solitary tubercle in the Gowers' tract on each side. Considerable work on the question of the number of segments involved in the crossing of the fibers from the posterior column of one side to the anterolateral tract on the other side followed this report, some observers believing that the crossing takes place in four or five segments, and others that it takes place in one segment.

The first to suggest making use of the information so gained was Schüller, who, in 1910, suggested section of the anterolateral tract for the pain of gastric crises. The operation was not performed, however, until 1912, when Spiller suggested it for the relief of pain in an inoperable tumor of the cauda equina. It was performed by Martin in the same year. It was performed again in the following year by Beer for malignancy, and in 1915 Souttar first performed it for the relief of gastric crises. Since then a number of cases have been reported, notably those of Frazier, Laighton, Peet and Horrax.

The operation itself is fairly simple, involving a laminectomy of about three vertebrae, with exposure of the cord and section of the anterolateral tract. The operation is usually performed at about the sixth dorsal segment, that being the easiest place to expose, but it may be performed at any place except in the region of the phrenic nuclei. High cervical chordotomies have been reported by two or three investigators.

The operation should not carry a higher mortality than posterior rhizotomy; it is rarely associated with bladder or rectal incontinence or paralysis of the extremities, and it does not seem to predispose to trophic disturbances. If performed for gastric crises associated with vomiting, it relieves the pain but will not relieve the vomiting, save in the sense that patients who have had a pain long associated with vomiting may be induced to vomit less when the pain is absent. The operation usually produces impotence.

Two patients were shown, one of whom had been relieved of pain from inoperable carcinoma of the bladder by bilateral chordotomy and the other of whom had been relieved of long standing, unexplainable pain in the left foot by right chordotomy.

DISCUSSION

Dr. Loyal Davis: Dr. Oldberg has given an interesting exposition of chordotomy. I wish to verify what he has said about the extensive sections of the posterior root that are necessary for the relief of various pains. Section of the posterior root was performed by me on a patient who had gastric crises of tabes. The posterior roots from the fourth to the twelfth dorsal vertebrae inclusive were sectioned bilaterally. I did this in two stages, and at the time of the second operation I inadvertently left the eight pair of thoracic roots. The patient continued to have the pain unabatedly. Later he passed out of my hands; the last report was that the gastric crises were still present. This would seem to indicate that a very small pathway is sufficient to transmit such types of visceral pain into the cord.

I was particularly interested when Dr. Oldberg drew the diagram of the operation, chordotomy, because he included some of the gray matter in the lesion. I showed some years ago that the visceral afferent fibers for pain ascend by short relays of neurons in the juxtagriseal matter, so that from a physiologic and anatomic standpoint one would not expect chordotomy to relieve visceral pain if only the anterolateral columns were sectioned, as is the practice in relieving somatic pain.

You may recall that Förster recently presented a case in which he had performed chordotomy for the relief of gastric crises. The patient died later, and microscopic specimens showed a definite destruction of the gray matter. I believe that it should be emphasized that a visceral pain, such as a gastric crisis, requires chordotomy that includes the gray matter in order that the visceral afferent impulses will be interrupted.

Dr. Percival Bailey: My experience has been that chordotomy in gastric crises stops pain, but not vomiting; also, that the patients continue to have shooting sensations in the legs, but these are "crawling" in type and not pain.

One patient said that he felt as if someone were tapping him on the leg with a hammer. One must be careful with male patients to warn them that they will be impotent following such an operation. They will have erections, but no ejaculations. That has been my experience; if the patients are not told in advance, they resent it.

Dr. Eric Oldberg: One interesting thing that Horrax remarked in his cases was that the fibers that convey pain from the lower segments as they cross over are crowded laterally by the higher incoming fibers, so that if one does a section for pain in the leg or foot, it is not necessary to go so deeply as when the operation is for pain in higher regions.

The Effect of Liver Damage on Nerve Tissue. Drs. Lathan A. Crandall, Jr. (by invitation) and Arthur Weil.

Recently, one of us (Dr. Crandall), with Cherry, demonstrated the presence of lipase in the serum of dogs following experimental damage of the liver and in patients suffering from liver disease. Such an olive oil-splitting ferment could also be demonstrated in the serums of patients with multiple sclerosis, which is similar to the increase in lecithinase shown by Brickner. The problem of this investigation was to find out whether, following experimental damage of the liver in dogs, substances could be demonstrated in the serum which would act destructively on nerve tissue, and whether such substances were related to the lipolytic ferments. Furthermore, a histologic study of the central nervous system was made as a control of the test tube experiments.

Following ligation of the common bile ducts in eight dogs, of the pancreatic ducts in seven dogs and the formation of an Eck fistula in three dogs, blood was taken at different intervals. Part of the serum was used for the determination of olive oil-splitting ferments. Another part was incubated with rats' spinal cord. After twenty hours the spinal cord was fixed, embedded and stained by different methods for myelin sheaths. On the first or second day following the ligation of the bile ducts or common pancreatic ducts there was a sudden rise in olive oil-splitting ferments, which normally are absent or present in only minimal amounts in the serum of dogs. On about the fourth postoperative day, the serums showed a markedly destructive effect on the spinal cord of rats. In longitudinal sections the outer zones were markedly edematous and showed a spongy appearance. Myelin sheaths and axis cylinders were swollen and distorted, and the glia nuclei had lost their staining qualities. This effect was still more marked on the seventh day and was still present in the serums taken three weeks after the operation. The lipase, however, had been diminished or had disappeared entirely after approximately seven days. No direct relationship, therefore, could be postulated between the increase in lipase and the destructive action of the serums on the spinal cord of rats. Furthermore, serums that had been heated for thirty minutes to 62 C. showed at different periods following the operation the same destructive effect as nonheated serums. Finally, the concentrated filtrates of serums that had been diluted with acidified water and heated to precipitate the proteins showed a marked effect on the spinal cord of rats similar to that which it showed on the urine of these animals.

Histologic examination of the central nervous system following experimental damage of the liver has been reported by Kirschbaum, Fuchs, Rapoport, Okada and others. They described generalized severe disease of the ganglion cells and mild proliferation of glia. Okada reported that he observed the changes in the ganglion cells in the brains of rabbits first on the sixth day following damage of the liver. In the brains of dogs with ligation of the common bile ducts and with Eck's fistula we found changes similar to those described by other observers. In addition, there were in two dogs with ligation of the common bile ducts excessive lesions and active glial proliferation, which had seemingly not been described before. In both dogs, ten days and thirty days, respectively, following operation, these lesions were found at the inner walls of the lateral ventricles.

The ependymal lining was edematous; in some places the ependymal cells were destroyed, in others they showed active proliferation. In the subependymal tissue there was an extensive status spongiosus, with severe destruction of all tissue elements. Surrounding this area a dense zone of glia nuclei was found; in it were large, round or more oval nuclei with scanty cytoplasm, sometimes showing lobulation of the nuclear membrane. In Holzer-stained sections of these regions the glia fibers were not sharply outlined, but rather diffusely swollen, in contrast to a dense fibrous gliosis in other parts of the subependymal tissues. Following the dense zone of glial proliferation there were active increase in fascicular glia and formation of glia rosets. The blood vessels in this region showed a diffuse swelling of their walls, but no perivascular infiltration was seen. The choroid plexus showed marked edema of its connective tissue and severe damage to the covering ependymal cells. In sections stained for myelin sheaths, round foci were seen in the white matter, which stained pale; in it myelin sheaths and axis cylinders were swollen. There was a mild edema of the pia-arachnoid covering the convexities and of the underlying outer layers of the cortex. The gradual decrease of the severity of the damage to nerve tissue from the wall of the ventricles toward the inner regions of the brain suggests that the toxic substances are eliminated through the choroid plexus into the cerebrospinal fluid. The similarity of the histologic changes to those reported in Wilson's disease, pseudosclerosis and other brain diseases correlated with disease of the liver was pointed out. The status spongiosus, with marked glial proliferation in the outer zones and the presence of the large glia nuclei, is like that which has been described in those conditions.

Disturbances of Reading, Writing and Arithmetic in the Infantile Cerebral Palsies. Drs. A. A. Low and J. K. Meyers (by invitation).

A boy, aged 13 years, with a complete motor and partial sensory aphasia of congenital or early infantile origin had been trained to copy with fair facility from script and print. In writing to dictation and after brief exposure he had considerable difficulty. An analysis of the mistakes revealed numerous errors of the kind that have been classified by students in "cerebral dominance" under the headings of "errors of orientation" (*b* for *d*, *p* for *q*, *f* for *t*, *u* for *n*) and "reversals in the direction of reading" ("was" for "saw," "no" for "on"). In the present case, the previously mentioned letters were frequently confused, but the confusion extended to other letters, too; for instance, to *i* and *o*, *i* and *e*. Most of the mistakes could be explained on the basis of perseveration, without invoking the principle of "cerebral dominance." The words, "thumb," "hand" and "finger" were pasted singly on pieces of cardboard and placed on the table. The patient then copied them correctly. The same series of words was then exposed in the identical order for from two to three seconds, and the patient was asked to write them. He reproduced "thumb" as "tingb," "hand" as "hanb," and "finger" as "fingb." Both from this performance and from suitable variations of the test it could be shown that the repetition of the b in "tingb," "hanb" and "fingb" was evidence of perseveration rather than of what the advocates of "cerebral dominance" call "errors of orientation." That the mechanism of perseveration is frequently resorted to by children who have been the victims of an infantile cerebral palsy was demonstrated by various samples of performances in arithmetic. One of the children produced the following additions: 9 + **2** = **12**; 4 + **8** = **18**; 13 + **7** = **17**; 6 + 7 = 8; in the last instance, the counting from 6 over 7 to 8 is essentially a perseverative process. Another child performed a series of additions with varying success. When he was then asked to execute subtractions, he persevered in the adding operation and produced the following performances: 12 — 3 = 15; 7 — 3 = 10; 13 — 4 = 17.

From these studies we draw the conclusion that, in our cases of infantile cerebral palsies at least, no definite inference can be drawn as to the mechanism of cerebral dominance from the so-called errors of orientation. The errors observed in our cases can be explained with greater plausibility as the result of the mechanism of perseveration.

DISCUSSION

DR. ROY R. GRINKER: What is Dr. Low's idea concerning perseveration? Does he use it as a descriptive term, or is there some concept fundamental to the understanding of the aphasias behind the term?

DR. D. P. BODER: I wish to ask Dr. Low what the eye preference of the child was. I have frequently found that children with a discrepancy in hand and eye preference present a difficulty in discrimination of directions, as revealed in letter reversals. Children with no definite hand preference, or those forcibly reversed from left to right, also show often very consistent difficulties in the drawing of a diamond. They may draw two or three angles of a diamond correctly and consistently be unable to close the fourth. Also the child, in addition to the other defects, may have an eye deficiency or an eye-hand discrepancy that in such cases, I think, should be ruled out.

DR. A. A. LOW: The child was not tested for eye preference. I do not see how that would affect the examination of this child.

DR. D. P. BODER: It may be an intermediate case. You can have some change in the brain of an animal that destroys the "hand preference" for fine performances such as grabbing food, while he still does other things, such as washing or scratching, with either or both hands.

DR. A. A. LOW: Dr. Grinker's question as to what is perseveration is most likely meant to ask for a definition of the term. I think that perseveration may be defined as a condition in which a newly offered stimulus provokes a reaction that is the adequate response to a previous heterogeneous stimulus. The phenomenon is well known from the aphasias in which a patient, after he is asked to open the mouth, continues to open it when the stimulus "close your eyes" is offered. I think that the charts here presented show precisely this type of an uncalled-for resumption of a reaction to a former stimulus. The patient wrote the word "finger"; when he was asked to write the words "thumb" and "wrist," he repeated the former reaction and wrote "thingb" and "wingt." The syllable "ing" from the word "finger" was perseverated in the two succeeding words.

As to Dr. Boder's question concerning the handedness of the patient, I wish to state that the child was right-handed, and wrote and ate with his right hand without special training in the use of the hand. He had difficulty in distinguishing the terms right and left in performance tests; but he had the same difficulties with all prepositional terms, like "above," "below," "beside," and the like.

PHILADELPHIA PSYCHIATRIC SOCIETY

Regular Meeting, Dec. 11, 1931

FREDERIC H. LEAVITT, M.D., *President, in the Chair*

SOME ASPECTS OF TREATMENT FOR DELINQUENT BEHAVIOR. DR. FREDERICK H. ALLEN.

Delinquent behavior does not represent a unit problem but involves conditions of varied etiology and therefore requires several different approaches in treatment. Behavior that is described as delinquent, to be understood, must be viewed as a human response to satisfy some striving or need of a person attempting to adjust himself to his own situation and to his environment. Treatment, to be intelligent, must be based on an awareness of what the behavior means to the person and of some of the conditions that cause the behavior to arise.

There are three major approaches in treatment which, although each overlaps to some extent the others, represent three rather distinct methods of treatment:

1. The more universal method of approach is that which depends on the use of authority. A certain amount of this authority operates automatically. When

a person violates a rule of society, community pressure is immediately brought to bear to bring him into conformity. This represents the general type of authority to which everyone must make an adjustment. Society has vested certain institutions with the direct authority to deal with deviations and gives them the power to punish or to correct. Into the operation of these organizations, however, have crept certain modifications of the use of authority which bring this method more in touch with the other two. This first method, used by itself, may have the effect of correcting a certain amount of delinquent behavior. When this behavior, however, emerges from conditions that are not touched by this method of approach, it is likely that the behavior will either continue or be converted into other forms of abnormal activity.

2. The second approach is largely sociologic and depends on changing the social situation and seeing in the social situation the causes for the delinquent behavior. In a broad sense this would include the relationships that the person has with other people and the attitudes that the latter take toward him, and treatment would be directed toward a better understanding and modification of the various things that may be creating delinquent behavior in the child.

3. The third approach recognizes that there are strivings and conflicts within the person that are motivating delinquent behavior. Treatment that depends on the use of authority or on social changes will be futile here. Treatment of persons with internal conflicts depends on the application of psychotherapeutic methods.

Each community should evaluate its resources for treatment in order to make sure that there are facilities to meet the demands of the three types of treatment, and that there is adequate correlation between the different organizations applying these methods of treatment. Organizations, the activities of which call for the application of the first two methods, should have available sufficient diagnostic resources to make certain that treatment of the different types is applied intelligently so that those needing psychotherapeutic treatment are not handled on an authoritative or a sociologic basis.

Broken Homes. Dr. Samuel Leopold.

An analysis of 100 cases of separated families that came before the Philadelphia Municipal Court showed the direct rôle played by such situations in the causation of delinquency. While the importance of many other etiologic factors is recognized, emphasis must be placed and attention must be focused on this environmental factor. In this study, over one half of all the children who came into the court were from broken homes.

The Relationship of the Psychiatric Clinic to the Juvenile Court. Dr. James S. Plant.

The Juvenile Court as a Social Instrument. Judge Paul N. Schaeffer.

In general, in common law a minor 14 years or over is presumed to be capable of forming a criminal intent and is, therefore, held subject to the penalties of the criminal law. Blackstone said that "infants under the age of discretion ought not to be punished by any criminal prosecution whatever." The report of the District Attorney of New York for the year 1822 showed 450 police cases of juvenile offenders. In the list are cases of boys 12 years of age who were sentenced to the penitentiary for six months for the offenses of begging, vagrancy or suspicion of theft.

It is generally conceived that the first definite advance toward the separation of juvenile offenders from those old in crime occurred in the City of Danzig at the opening of the last century. Mr. Clement Griscom, a Quaker from Philadelphia, was so much impressed by his visit to the institution founded at Danzig that on his return to this country he was successful in interesting people in New York and Philadelphia in the proper treatment of minor offenders. This

led, in 1823, to the formation of a society for the reformation of juvenile delinquents in New York. The efforts of this society led to the establishment of the New York House of Refuge, which was opened in January, 1825, and which was the first institution in America for juveniles. They have taken the advanced position that the objects of the criminal law should be, first, the protection of society, and, second, the reformation of the offender.

The idea of separate institutions for juvenile delinquents spread rapidly throughout the country, but as time went on it was seen that these institutions, founded on the high principles of humanity, did not fulfil the purpose of reformation. It was found that their discipline was too severe, that there was little individualization of treatment and that the buildings erected were ill adapted to effect the ends desired. It may be due to the fact that the lives of the boys and girls in these institutions were so far from normal that the results were discouraging. About a generation ago, there came a reorganization of the houses of refuge. The Boys' Department of the Philadelphia House of Refuge was moved to Glen Mills, in Delaware County, and a new institution was erected on the cottage plan which had been developed in France. Later, the girls' institution was moved to Darlington, where it has taken the name of Sleighton Farms School for Girls.

During this time, however, juvenile offenders were still arrested, held for court and tried and sentenced in the courts according to the same procedure that was applied to adults. It was not until about the middle of the last decade of the last century that the first juvenile court was established in Chicago. In 1901, the Legislature of Pennsylvania enacted the State's first juvenile court act. The act of 1903 provides that the juvenile court shall be a division of the courts of quarter sessions, which is given full and exclusive jurisdiction in all proceedings affecting the treatment and control of dependent, neglected, incorrigible and delinquent children under the age of 16 years. The act provides that all sessions of said juvenile court shall be held separate and apart from any session of the court held for the purpose of its general criminal or other business, and the records of the proceedings shall be kept in a docket, separate from all other proceedings. The act also contains a prohibition against the commitment by any magistrate or justice of the peace of a child under the age of 16 years to an institution for correction or reformation.

By the act of July 12, 1913, there was created the Municipal Court of Philadelphia. The president judge of the municipal court is directed by the act to designate a member of the court to hold juvenile court, the assignment to be for a period of one year or longer in the discretion of the president judge. The decisions of the appellate courts have been in accord with the spirit of the Juvenile Court Act. The ideas of punishment, revenge and retaliation have no place in the juvenile court.

Notwithstanding the splendid advance in practical humanitarianism manifested by the passage of the Juvenile Court Act and by other social legislation, and in spite of the peremptory language of the act of 1903, some counties of this state have been slow or even loath to establish real juvenile courts. When, three years ago, I asked one of their judges if they made use of the services of a psychologist or a psychiatrist, he scoffed at the idea.

It will be noted that there are two methods by which the case of a child can be taken into the juvenile court: first, by a simple petition addressed to the court, and, second, by the certification of the magistrate's transcript to the juvenile court by either the district attorney or the judge of the court of quarter sessions. I believe that the method by petition is far preferable. In this way the probation officers learn the facts at first hand, and the child is spared the experience before the magistrate. The room in which sessions of a juvenile court are held should be simple and cheerful. There should be plenty of natural light. The room should not be too large — merely large enough to provide sufficient chairs for the seating of the maximum number of children, parents, probation officers, witnesses and social workers that appear in the average single case. In my opinion, it is preferable to have the judge sit at a table rather than on a bench. The child

should take his seat across the table from the judge. Each case should be heard privately. The sessions are not secret, but neither should they be open to general curiosity seekers. Any person who has a legitimate interest in the case before the court should be admitted, but no others. Above all, there should be no newspaper publicity given to the hearing. As it is the entire purpose of the act to shield the child, the court, in my estimation, has authority to exclude newspaper reporters. The delinquencies and misfortunes of children should not be regarded as news.

When a case is called and the child has taken his place before the judge, every effort should be made to put the child at his ease so that his mind can function normally. The first question should be framed to that end rather than for the eliciting of important information. After he has been answering readily and appears to be composed, one asks him: "now, tell us why you are in court this morning?" In the majority of cases this is followed by a truthful and generally sufficient statement of the actions that have led to the complaint. Complainants usually state that the boy or boys have told the whole truth. In all cases in which any undue retardation in school appears, the child has been examined by a psychologist and sometimes by a psychiatrist. I am interested in the degree of oversight the child has received at home. After all the facts appearing in the case have been presented, there is a conference between the judge, assistant district attorney, probation officers, and sometimes social workers to determine the course to be followed. In general, if the child has never been before the court, one will try probation in cases in which the home conditions are not so unfavorable as to require the transfer of the child. If, however, the child has been placed on probation and has been guilty of other delinquencies, or if the home life is such as to make advisable the removal of the child therefrom for his own safety, there are two expedients: The first, the more usual, to place him in the Boys' Home. In every respect it is endeavored to give it the atmosphere of a home rather than of an institution; commitment to it usually amounts to no more than a transfer from the parental home to this Boys' Home. In addition to the Boys' Home, foster homes are sometimes used. Second, commitment to a protectory or a reformatory is possible. I believe that such a commitment amounts to a confession of failure on the part of the court and other welfare agencies of the community in the particular case, for the rigid discipline and unnatural life of the average reformatory hardens the boy and destroys much of the idealism that is in him. Each case that comes before the court presents a distinct and separate problem. The case of each boy must be approached with sympathy and in an endeavor to understand the problem from the boy's point of view, and then ingenuity must be exercised to bring into play the proper correctives.

The expediency of continuing juvenile cases for a month or longer frequently operates successfully. Last spring, I had in court several boys whose records were poor and whose conduct was trying. I had some of them in court last week, at the expiration of a six months period of probation; in each case the reports of police, teachers, parents and probation officers were that the boys had done so well that they had no complaints concerning them.

The strongest and most lasting impression made on me by my eleven years' connection with the juvenile court is the truthfulness and manly instincts of the average boy. I believe that I can safely say that 90 per cent of boys who come before the courts answer all questions truthfully. Threats and fear are capable of distorting a boy's story. On the other hand, I have known boys who, after having given me their sincere promise to refrain from certain conduct and shortly thereafter being brought in because of a repetition of that conduct, have demanded that they be punished and sent away.

Of course, not all cases are those of delinquents. The court undertakes to exercise jurisdiction over the other class of cases in which jurisdiction is confered by the act of 1903, namely, incorrigibility, neglect and dependency. In cooperation with the Berks County Children's Aid Society, a number of dependent children are placed in private families each year. Although this work is properly the function of the Board of Poor Directors also, cases arise in which it is

advisable to have the order of the court give authority to the supervision and placement. In accordance with the act, the court, of course, desires to have free homes procured for the children, but this cannot always be done promptly. In such case an order of support for a definite period is made, at the end of which the child is brought to court, and if it seems certain that the child's welfare is subserved the order is continued for another period. In doing work of this kind, it is realized that the court is not following the program of the Children's Division of the Public Charities Association of Pennsylvania. There are some leaders in child welfare who believe that dependent and neglected children should be saved from the taint of appearance in court, and that the court should confine its activities to cases of delinquency and incorrigibility. However, the appearance of a child in the juvenile court should not be thought of as disgraceful to the child, but the juvenile court should act as a social agency in cases that are not handled directly by other agencies. Indeed, to be of the greatest value in its community a juvenile court should be a social institution; it should not be merely a piece of legal machinery.

DISCUSSION

Dr. Henry I. Klopp: I have come to believe that the majority of persons who become criminals started the criminal career within the juvenile period. There are certain types regarding which I coincide in the opinion expressed that the outlook is far from encouraging; nevertheless, I am inclined to be optimistic in the belief that if these cases are taken in hand early something can be accomplished. I make this statement from experience. The moron and the psychopathic personality types of delinquency are definite problems and require a long period of habit training under careful psychiatric guidance. Without discrediting the state schools for the care of these types of persons, I am convinced that a certain percentage can be better guided in hospitals for mental diseases. This statement is made for the reason that some of the delinquents have been previously in jails and in state schools. After they are admitted to a hospital for mental diseases they seem to come to a realization of their past shortcomings. One cannot overlook the environment in these cases. Nothing can be accomplished unless the patient is treated as an individual. In addition there is the influence of the personality of the psychiatrist who comes in contact with the patient.

The juvenile delinquents who come to the Allentown State Hospital for the most part present extreme cases. After everything else has been tried, and in order to obtain an interpretation of the case, good judgment is used in the commitment to the hospital. Diagnosis should not be the first thought, but the consideration of the patient *per se*. On this basis, treatment is given in accordance with the condition presented by the patient. Fifty per cent of the juvenile patients admitted to Allentown are placed on the records as without psychosis. One fact which Judge Schaeffer touched on should be more definitely emphasized, namely, the authority and influence of the school. One must not overlook that impressions made on a child before he is 6 years of age are lasting. In the public schools, there are teachers who do not understand and hence do not interpret the conduct disorder of the child correctly. It is important that school authorities recognize that a child who does not do well in one school should be placed in another where he may possibly be better understood.

My experience has been that the judges of the juvenile court are progressive and are endeavoring to interpret the juvenile offender and to help him. From a psychiatrist's standpoint it is not a question of labeling the child but of placing before the judge the mental, physical and social history in the case, thereby presenting a clear picture. For this purpose a survey letter describing the case, with suggestions, is submitted to the court. One must keep in mind that in many of these patients nothing can be accomplished in a short time. It sometimes takes months and in some cases even one, two or three years.

There is another important factor. When these delinquents are returned to the community without a definite follow-up system through a social service department they will become recidivists, just as when they are released from a state

school. I have in mind two boys who were committed, in accordance with the provisions of the 1923 Mental Health Act, for observation, diagnosis and treatment. They held up an automobile and pointed a gun at the occupants tô obtain money. Every effort was made by the attorneys for the respective families to have the boys leave the institution during the holiday season. This was refused, and the court did not interfere. These boys were eventually furloughed in the care of the social service department. One from the first has done well; the other for some time wavered; there was not the proper parental guidance, and he required close social service supervision. I am pleased to be able to report that he is now doing well. Some of the boys and girls have been permitted to attend the public school in Allentown, going back and forth each day from the hospital. Thus far we have not had any failure in this direction.

As I have already stated, one cannot overlook diagnosis. Some of the children present cases of postencephalitis and show particular problems. The children are not understood in the community, and until they are studied they suffer abuses. I am in hearty sympathy with the commitment of children with cases of juvenile conduct disorder, including delinquents, to a hospital for mental diseases for observation, diagnosis and treatment. In addition, if one is to accomplish anything in the prevention of criminality, one must begin with the juvenile delinquent before he enters the adult stage and becomes a criminal.

Dr. Charles W. Burr: As I have said previously before this society, the thing that I have been thinking about most has been the history of the attitude of law toward crime. Some of the primitive peoples of today, or the peoples called primitive, believe in the golden age. Among certain of the African and Australian tribes, who represent man at his simplest, law is retaliation and no more and is really private war. There is no state. It is recognized by their society, as it exists, as being right and proper, if John Smith kills Tom Brown, that Brown's family may kill Smith or if they wish they can receive money or its equivalent, and the affair is settled. That is the beginning of law. I do not think that even with as intelligent and farsighted a man as Moses, or in what we call the Mosaic law, did the idea of reform enter at all. It was punishment that was always thought of. The next step was that punishment was determined by examination, and the following step is recent. In the early part of the nineteenth century or the latter part of the eighteenth century it was realized that punishment was not only retaliation but actually was to reform the criminal. That I think is a very modern idea. I do not think that it existed in ancient or medieval times or until recently. Solitary confinement in this state started as a measure of reform for the sake of the criminal. The Quakers instituted solitary confinement at Cherry Hill in order to give the criminal time to think over his sins so that he might reform. It did not work, although the object was to help the criminal; it was not to make a hardened criminal of him but to do him good. That I think was one of the first movements — not only to punish but to turn the criminal from his bad ways into the straight and narrow paths. It is within my own professional lifetime that men have begun to have the thought, which Dr. Plant spoke of as being along the same lines as the prevention of disease: "Can we not do something toward the prevention of crimes?" Can one do something to prevent crime and to obtain a smaller percentage of criminals than exists today? All of the men who were back of the municipal court movement had in the backs of their minds the object that they could change the legalistic aspect and the attitude toward crime and do something to prevent crime rather than to cure criminals. But to prevent protoplasm from going bad was one of the chief purposes of the man who started the movements for municipal courts and other institutions, where the child would not be treated as a criminal but by proper handling might be cured. What is going to come out of it all no one knows. I think that both the judge and the psychiatrist are at sea, in fact, very much at sea, and I think that they are sailing along a very wide sea with compasses that have been magnetized and wigwag in many directions. I think that one has come this far — that crime is a thing that one should try to prevent, and that probably it can

be decreased. But when it comes to the therapeutic measures that have been proposed, there might be mentioned one that people belonging to the criminal class should be executed. All the same, I believe that somewhere, some time, some one will find a way of greatly decreasing the number of criminals that are being bred at present.

BOSTON SOCIETY OF PSYCHIATRY AND NEUROLOGY

Three Hundred and Ninety-Seventh Meeting, Jan. 21, 1932

A. Myerson, M.D., *Presiding*

The Cortical Representation of Certain Postural Reactions and the Normal Functioning of Cortical Remnants. Dr. Philip Bard.

While exhibiting approximately normal walking and running, a cat that has survived bilateral removal of the neocortex for more than two years has shown a tendency to assume peculiar attitudes of the legs when standing or sitting. These consist of crossing, abduction or retroposition of the fore legs and abduction or forward extension of the hind legs. Another cat (shown at this meeting), which in addition to total bilateral cerebral decortication has been deprived of most if not all of the substance of the corpora striata, exhibits the same postural deficiencies.

Analysis has indicated that these attitudinal peculiarities have their basis in an absence or deficiency of certain reactions described by Rademaker (Das Stehen, Berlin, Julius Springer, 1931) and shown by him to be necessary for normal standing. These are: (*a*) placing reactions (manifestations of *Stehbereitschaft*), which he has found to be wholly absent after complete decortication and absent in the contralateral legs after removal of one entire hemisphere, and (*b*) hopping reactions (*Hinkebeinreaktionen*) which, according to the author, merely become retarded and hypermetric in dogs after decortication. Rademaker has presented good evidence that the placing reactions are conditioned responses, and I concur in this opinion.

In the cat, the placing reactions are as follows: If the normal animal is suspended with legs down and the chin is touched to a table edge, the fore feet are at once raised and placed beside the jaws, and the legs are extended to a standing position. If the backs of the feet of such an animal are lightly touched to a table edge they are instantly placed on the table. If the fore legs or hind legs are pulled or thrust over the edge of a table on which the body rests, they are at once brought up, and the animal may then stand. If any leg of a standing cat is passively abducted without being held, it is quickly replaced in the standing position. All these reactions occur with normal promptness and facility in blindfolded animals.

The hopping reactions are evoked when any leg of a suspended normal cat is placed in a standing position and the trunk displaced laterally or backward. With slight displacement the supporting tone diminishes, and the foot hops in the direction of the displacement, so that the leg is maintained in the standing position.

The two decorticate cats and cats lacking frontal poles only (ablation of the sigmoid gyri and of immediately adjacent tissue) showed bilateral absence of placing reactions and absence or great retardation with marked weakness (hypometria, never hypermetria) of the hopping reactions in all four extremities. The same bilateral abnormalities were presented by two cats in which one entire hemisphere and only the sigmoid gyri and gyrus proreus of the other hemisphere had been removed. Ten unilaterally decorticate cats and eight animals that had suffered extirpation of only one frontal pole have been studied for from one to twenty-seven months, and each of these animals has shown permanently in the legs contralateral to the lesion the same deficiencies seen in all the legs of animals

on which bilateral operation was performed. Furthermore, in three cats removal of all brain tissue above the hypothalamus on one side produced no greater postural abnormalities than did removal of the sigmoid gyri and gyrus proreus on one side in other cats.

Such operations as ablation of an occipital pole, of one entire temporal cortex of a gyrus proreus or of the caudal half of both hemispheres left the placing and hopping reactions normal.

The fact that removal of scarcely more than the electrically excitable parts of the sigmoid gyri causes as marked deficiency in the placing and hopping reactions as complete decortication indicates a definite localization of the cortical representation of these functions. More definite proof of this was afforded by three cats on which unilateral operation was performed in which autopsy showed that there remained of the cortex of one hemisphere only a fragment consisting of the gyrus proreus, the sigmoid gyri and the small amount of cortex lying ventral to the lateral extremities of the sigmoid gyri. In spite of this huge ablation, all these animals showed equal and normal placing and hopping reactions of both fore legs. In other words the cortical remnant of one side managed these reactions as well as did the entire cortex of the other side. In each case the reactions of the hind leg contralateral to the remnant were somewhat below par. This was correlated with extension of the deep ablation forward to the caudal edge of the hind leg motor area on the posterior sigmoid gyrus; on exploration of the cortex with electrodes this area showed a raised threshold and a weakened response as compared with the homologous area of the other hemisphere. On the other hand, the fore leg motor areas of the two sides gave equal responses and showed equal thresholds. This suggests that the motor areas for the legs represent the essential cortical mechanism for these postural reactions, but another interpretation is possible. In these animals the fore leg sensory zone which, as delimited by Dusser de Barenne (*Quart. J. Exper. Physiol.* **9**:355, 1915), overlaps the fore leg motor area was left intact well within the remnant, whereas the hind leg sensory zone situated in the longitudinal gyrus just behind the sigmoid region was removed. In favor of this interpretation is the fact that when in two cats the remnant included this hind leg sensory zone the placing and hopping reactions were normal in both the contralateral legs. On the other hand, two cats presented wholly normal reactions after removal of only one hind leg sensory zone.

A cat that has been deprived of the entire right cerebral cortex and retains of the left cortex only a remnant consisting of the sigmoid gyri, the gyrus proreus, the coronal gyrus and the rostral extremity of the longitudinal gyrus was presented at the meeting. While the placing reactions of the left legs were wholly absent those of both right legs were normal. The hopping reactions of the right legs were normal, and those of the left legs extremely deficient.

The consistency of the results obtained from the variety of experimental cortical ablations used in the analysis of this problem makes it difficult to think of these cortical reactions as the manifestations of any sort of "mass action" of the hemisphere or hemispheres as a whole, or as the results of a spatially extensive "configuration" within the cortex. In short, it seems clear that the essential central representation of these particular reactions, which have the character of conditioned reflexes and are in all probability learned behavior patterns, is strictly localized and is remarkably independent of all other parts of the cortex.

DISCUSSION

Dr. D. Gregg: Is there any evidence that with the passage of time there is any tendency for function to return?

Dr. D. McPherson: Is it possible for these reflexes to be present in the entire absence of the sensory cortex?

Dr. D. Gregg: Is the general behavior of the cats altered in any way; that is, so to speak, is the cat's personality changed?

Dr. A. Myerson: Are the cats more easily excitable and angered?

Dr. P. Bard: In cats kept as long as four and a half months after removal of one frontal pole there was, apart from the rapid immediate recovery following operation, no change as regards these reactions. I was particularly interested in this point, and spent considerable time in an effort to determine the facts. I should say that the answer to Dr. Gregg's first question is distinctly, "No." In the animals that showed normal reactions and had left only a cortical remnant, that remnant invariably contained both the fore leg motor area and the fore leg sensory area; in the cat the areas overlap. It also contained the hind leg motor area, but in some cases showing nearly, but not quite, normal reactions of the contralateral hind leg, the hind leg sensory zone had been removed. In making these statements I am following the delimitation of the representation of cutaneous and deep sensibility in the cat's cortex as given by Dusser de Barenne. I regard his as the best work on this subject. He employed the method of localized application of strychnine, which yields an exaggerated sensory effect in place of the sensory deficit that results from cortical extirpations and that is very difficult to study. Removal of nearly all of Dusser de Barenne's hind leg sensory zone does not affect these reactions. Yet when this area is contained in a remnant that also contains the motor area, the reactions are entirely normal, whereas they tend to be somewhat subnormal when only the motor zone is contained in the remnant. While the motor and sensory fore leg areas overlap and cannot be separately extirpated, the two areas for the hind leg occupy separate zones of the cortex and can be removed individually.

I found that some of the cats had changed. For example, after extensive ablations they became rather filthy; instead of licking themselves, they licked the floor. The totally decorticate animals are more easily excitable and angered. If one pinches their tails only moderately they become infuriated, and attempt to strike, hiss and growl.

Jacksonian Attacks and Tumor of the Brain. Dr. E. W. Taylor.

The following cases are reported, with special reference to the first, in order to emphasize the importance of jacksonian attacks in relation to tumor of the brain.

Case 1.—A man, aged 41, in 1917, while in war service, was inoculated for typhoid. Immediately after a second inoculation he was found unconscious. He underwent a third and a fourth inoculation with no untoward results. A year later, in France, he had a second attack of unconsciousness. Following the war he was active in business in spite of increasingly frequent seizures affecting the right facial nerve only. So far as was learned, the original attacks were accompanied by more or less general convulsive movements, which later gave place to purely focal attacks in the face. In general, the patient's health was in no way affected. His wife, however, had noticed a certain change in personality. The individual seizure, many of which were observed was as follows: He became abstracted and stopped speaking, and in a few seconds definite twitching of the muscles on the right side of the mouth developed, finally involving the entire facial distribution on that side. Except for the violent spasmodic movement of the face the patient appeared to be in no distress. After about a minute, the twitching ceased, and he quickly became normal again, except that speech was somewhat confused for a time. The pulse rate was not elevated, and it was not difficult to determine that the patient remained conscious throughout. The attacks increased in frequency until he was having as many as twenty or more a day, and they became apparently more violent.

Physical examination gave negative results, except for an initial spinal fluid pressure of 260. Roentgen examination showed a small area of calcification in the left frontal lobe and distortion of the ventricles was revealed by encephalography.

On the basis of these findings, the patient was operated on by Dr. W. J. Mixter; an infiltrating tumor occupying the posterior portion of the left second

frontal convolution was revealed. No attempt was made to remove the mass. For some unexplained reason the patient died on the following night.

Necropsy showed the tumor to be a fibrillary astrocytoma, infiltrating the brain for several centimeters, impinging on and possibly invading the precentral convolution.

The interest of the case lies in: the extent of the lesion with the practical absence of indications of increased pressure during life, the long duration of the jacksonian attacks and the sharp localization of the clinical manifestations to the face in spite of the apparently close proximity of the tumor to the arm area. The diagnosis of a tumor was rendered practically certain through roentgen examination and encephalography. Except for these aids, the only indications of a tumor during life were a change in the patient's personality and a slightly increased cerebrospinal fluid pressure.

Case 2.—In this patient, who likewise had general attacks at first, presumably with loss of consciousness, focal seizures developed later which involved the left arm and face and were combined with definite astereognosis and weakness of the arm. An encephalogram showed an air-filled space over the cortex in the arm area. The question of operation in this case should be seriously considered.

Case 3.—In a man, whose first symptoms were epileptiform attacks involving the right side rather more than the left, choked disk developed later, which established a diagnosis of a tumor. Operation over the left frontal region revealed a new growth. The patient's headache was much relieved, but aphasia supervened, which had not been present before and which persisted to the time of death, six months later.

Necropsy showed a tumor combined with a periosteal cyst, which connected with the lateral ventricles, and hydrocephalus.

Case 4.—A woman, aged 22, had vague headache as the first symptom, and later blurring of vision, followed by jacksonian-like attacks involving the left arm. Later, there was an increase in the severity of the attacks, which ultimately resulted in generalized convulsions. A diagnosis of a tumor was made. Operation was performed by Dr. Harvey Cushing, a large meningioma being removed from the region of the motor cortex. The patient recovered sufficiently to lead an active life for a number of years, although epileptiform seizures continued at infrequent intervals. In cases 3 and 4 an earlier operation would have been desirable.

Case 5.—A man, aged 24, for many years had had attacks of migraine beginning with sensory disturbances usually in the left hand and arm, which closely simulated a jacksonian attack at the beginning. This case, in contrast to the others reported, which showed definite organic lesions, illustrates a possible difficulty in diagnosis.

Comment.—Operative treatment remains the most rational method and should be undertaken in practically all cases in which there is definite indication of the seat of the lesion as shown by jacksonian attacks. The special points to be emphasized are: first, the frequency of tumor as a cause of focal seizures; second, the difficulty, at times, of diagnosis, particularly when the motor cortex is not involved in the absence of increased intracranial pressure; third, the value of roentgen examination and encephalography in arriving at a diagnosis, and, fourth, the importance of early surgical treatment.

DISCUSSION

Dr. W. J. Mixter: In case 1, lumbar puncture showed an initial pressure of 250. Encephalograms were positive. The presence of calcification within the cerebrum was of great importance in the making of the diagnosis in this case. At the time of operation it was evident that complete removal of the growth was impossible. Any attempt to block it would have caused not only paralysis but aphasia. It did not seem wise to do such a prolonged operation as that. A small piece of tissue was taken at operation from the front edge of the mass;

as Dr. Taylor said, the patient's death was not explained by the observations at autopsy. A number of patients who have tumors of the brain are operated on, make an apparent recovery and then die, and at autopsy there is little that explains the fatal ending. Dr. Kubik has recently done an autopsy on a man who died twenty-four hours after operation; the autopsy failed to reveal the cause of death other than the partial removal of a superficial tumor, with the cranial cavity apparently in good condition. It seems to me that the study of physical epilepsy is taking a new lease of life. I think that it is important that it should. I think that more stress should probably be laid on history. One should endeavor to get from observers — nurses and members of the family — a sharper history of the attacks. Some trained observer should be with the patient.

Dr. C. L. Kubik: Dr. Taylor has already spoken of the gross pathologic process. Histologically, the tumor in case 1 was an astrocytoma of the fibrillary type.

Dr. J. B. Ayer: Have you any theories as to the cause of the death of this patient?

Dr. C. L. Kubik: No. There was almost no bleeding; evidences of trauma were slight, and there were no signs of generalized increase in the intracranial pressure.

Dr. C. A. McDonald: I saw this patient before the operation and conferred with him and with Dr. Mixter. The size of the tumor was startling in consideration of the paucity of clinical signs. This case brings to attention the importance of jacksonian seizures, and I hope that Dr. Taylor will state what he means by a jacksonian seizure. Some writers speak of jacksonian attacks with consciousness and some refer to attacks without consciousness. Dr. Taylor referred to the report of Fincher and Dowman of 130 cases of epileptiform seizures of jacksonian character. Today I happened to be reading this report, and was attracted by the number and grouping of the cases: Twenty per cent were associated with trauma occurring after birth, 14.6 per cent with birth trauma, and 10 per cent with postinfectious conditions. These observers draw material from a wide area and hence may have seen many extraordinary cases, but I am sure that in my experience I have not seen so large a percentage of jacksonian-like seizures following birth traumas, traumas after birth and postinfectious conditions.

Dr. M. Yorshis: In the three cases tumor of the brain that came to autopsy at the Worcester State Hospital during the past year, two patients gave a history of "spells" and a diagnosis of epilepsy had been made before admission.

The first case was that of a woman, aged 45, who had had spells since the age of 39. She had been hospitalized twice during the previous year at a Boston Hospital, was thought to be epileptic, and was advised to report to the outpatient department. At the onset of a spell, clonic contractions were most intense in the left hand and arm and then became generalized. Since the onset of the spells, in 1925, the patient's personality had changed. She became fault-finding and irritable, and took less interest in the house than formerly. She reminisced freely and treated her husband badly. Physical examination at the time of the first admission to the Boston Hospital revealed difficulty in the recognition of odors. There was a palsy of the lower part of the left side of the face, and the tongue deviated to the left. Roentgen examination of the skull showed three small calcified areas in the region of the pineal body, which were interpreted as probable pathologic concretions; on stereoscopic examination the concretion seemed to be in the right temporal region. The husband noticed that the facial asymmetry, which occurred after the patient had had a spell, seemed to be more pronounced after an attack. When she was hospitalized at Worcester, physical examination gave negative results except for paralysis of the seventh cranial nerve on the left. On the twenty-second day after admission, the nurse found the patient becoming stuporous, and she died shortly afterward. The outstanding signs in this case were of a sensorimotor character, involving the left side of the face and the left arm and hand, and pointing to a tumor of the right temporal lobe, which was confirmed by autopsy.

The second case was that of a woman who showed a symptom complex of seizures occurring at the age of 43. Associated with this was an early onset of a mental picture consisting in alterations in character and temperament, intellectual dulness, and failure of memory, with localized signs such as optic atrophy and facial asymmetry. An antemortem diagnosis of a psychosis with epilepsy was made, but at autopsy a large glioma was found on the inferior surface of the left frontal lobe. The left pupil was fixed to light and in accommodation; the colloidal gold curve in the spinal fluid was 4455442100.

I think that Dr. Taylor's emphasis on the value of consideration of seizures as a symptom only, especially after the age of 30, is justified.

Dr. J. B. Ayer: I remember that Dr. Taylor told us in our neurologic classes, long before Dr. Penfield went to medical school, that anybody who began to have jacksonian attacks after the age of 30 should be suspected of having a tumor of the brain. While everyone realizes that jacksonian epilepsy may precede a demonstrable tumor of the brain by a long period, one does not, I think, expect it to occur fifteen years before the onset, and in two cases tumors have been demonstrated, one fifteen years and the other fourteen years after such premonitory symptoms. This is a most important matter to stress. Nor is jacksonian epilepsy alone to be considered as an early symptom of tumor. Dr. Taylor will remember a case that we saw together a year ago, in which petit mal attacks alone preceded a demonstrable tumor by several months. At present, my associates and I have at the hospital a patient who was recently at the Bellevue Hospital and was discharged with a diagnosis of idiopathic epilepsy. His mother and his grandmother had had epilepsy. He now has bilateral choked disks, and almost surely a tumor of the frontal lobe. Dr. Taylor's paper is very timely in emphasizing the importance of epilepsy as a prodromal symptom in tumor of the brain.

Dr. T. J. Putnam: The standard neurosurgical rule has been that a patient with focal attacks followed by weakness and increased reflexes should be explored whether evidence of increased pressure is present or not. The advance in laboratory diagnosis has added a few other indications. One is the presence of calcifications as shown by the x-ray. Good stereoscopic films and a skilled examiner are essential. Another is the demonstration of increased pressure by lumbar puncture at a stage when the disks are normal and the patient has no headache. The pressure need not be very high, and indeed a normal pressure does not rule out tumors of the brain. The tumor that Dr. Taylor showed was fibrous and probably relatively benign. It is always difficult to know what to do with a tumor on the left side. In some instances the damage caused during removal is greater than that caused by the tumor, and in other cases it is less. I remember such a case in which only partial removal could be carried out. The patient recovered from the aphasia and went back to work for two years, and then had a second and later a third partial removal. On the other hand, with extremely malignant tumors, the slightest interference with the growth may cause edema of the hemisphere or a rapid progression.

Dr. E. W. Taylor: Apparently, opinions differ as to what one should call jacksonian epilepsy. It has in general seemed to me best to limit this term to focal attacks not associated with loss of consciousness. This was Jackson's original idea, and it seems in many ways desirable not to extend the term to include localized attacks that may be accompanied by loss of consciousness. It naturally happens that as the irritative lesion increases, what was originally a jacksonian attack in a narrow sense finally may pass by gradations into more extensive involvements, finally very possibly becoming generalized. Penfield in a recent important paper enlarged on this general subject and stated that all epileptic seizures should be regarded as having a physical basis.

Dr. Ayer's memory is much better than mine. I am glad that I may have said something that Penfield has said later. From the point of view of treatment, his paper on cerebral injuries is a most valuable contribution; he demonstrated

that a cleancut resection of the part of the brain cortex from which the attack originates is the operation of choice rather than apparently less drastic measures which lead to complicating secondary conditions. Dr. Putnam's suggestion of increased spinal fluid pressure is important. Whether such pressure existed five years ago is an interesting question. His explanation as to why a general attack should become focal, as apparently occurred in my case, does not seem convincing. I do not see why the existence of a focal attack should exclude a general one, or why with the increase in the size of the tumor the generalized attacks should not continue even if the focal attacks become more pronounced.

Book Reviews

Cytology and Cellular Pathology of the Nervous System. Edited by Wilder Penfield, M.D. Three volumes. Price, $30. Pp. 1280. New York: Paul B. Hoeber, Inc., 1932.

No better evidence of the progress of neurology in the last decade can be offered than this three volume contribution on the "Cytology and Cellular Pathology of the Nervous System." That this is due in large part to the newer histologic methods is acknowledged by the fact that these volumes are dedicated to Ramón y Cajal. Not only have such methods enhanced the knowledge of normal cytology and cellular pathology and brought about a reconstruction of ideas in neuropathology, but they have undoubtedly caused a widening of knowledge and conception of the physiology of the nervous system and clinical neurology as well, so that the modern neurologist who essays, for example, to diagnose tumors of the brain clinically must have a workable knowledge of the natural life history of such tumors.

A glance at the contents of these volumes demonstrates the fact that no one person could possibly know or have written what is here contained. The editor therefore has wisely chosen the preeminent workers in the various specialties and has gathered around him the most important contributors in their lines from various countries.

It is difficult and practically impossible to review adequately a work of this kind. Volumes 1 and 2 take up the cytology and cellular pathology of the nervous system in health and disease without treating the disease entities under separate headings. In them the anatomy and the pathology of each cell group are described in turn, thus presenting information that is prerequisite to the understanding of more specialized work. The third volume contains studies of certain pathologic entities for which the more fundamental contributions in the previous volumes are a preparation.

Wisely, each author is solely responsible for the opinions expressed. The subject divisions, titles and authors are as follows:

I. The Neurone: General Character. E. V. Cowdry, St. Louis.
II. The Principles of Development of the Nervous System (Neurobiotaxis). C. U. A. Kappers, Amsterdam, the Netherlands.
III. Sensory Ganglia of the Cranial and Spinal Nerves: Normal and Pathological. F. de Castro, Madrid, Spain.
IV. Histopathology of Nerve Cells. M. Bielschowsky, Berlin, Germany.
V. Sheaths of the Peripheral Nerves: Nerve Degeneration and Regeneration. J. Nageotte, Paris, France.
VI. Nerve Endings: Motor and Sensory. J. Boeke, Utrecht, the Netherlands.
VII. Sympathetic Ganglia: Normal and Pathological. F. de Castro, Madrid, Spain.
VIII. Nerves of the Blood Vessels, Heart, Meninges, Digestive Tract and Urinary Bladder. P. Stöhr, Jr., Bonn, Prussia.
IX. Neuroglia: Normal and Pathological. W. Penfield, Montreal, Canada.
X. Microglia. P. del Rio Hortega, Madrid, Spain.
XI. Choroid Plexus and Ependyma. E. Agduhr, Uppsala, Sweden.
XII. Cerebrospinal Blood Vessels. Stanley Cobb, Boston.
XIII. The Meninges. Lewis H. Weed, Baltimore.
XIV. Pineal Gland. P. del Rio Hortega, Madrid, Spain.
XV. Hypophysis Cerebri. Paul C. Bucy, Chicago.
XVI. Retina, Chorioid and Sclera. L. B. Arey, Chicago.

XVII. Optic Nerve and Papilla. William Cone and J. A. McMillan, Montreal, Canada.
XVIII. Primary Tumors of the Brain. Percival Bailey, Chicago.
XIX. Tumors of the Sheaths of the Nervous System. Wilder Penfield, Montreal, Canada.
XX. Primary Tumors of the Spinal Cord and Intradural Filum Terminale. J. W. Kernohan, Rochester, Minn.
XXI. Tumors of the Optic Nerve. F. H. Verhoeff, Boston.
XXII. Tumors of the Retina. Roy R. Grinker, Chicago.
XXIII. Tumors of the Chorioid and Allied Tumors. Jonas S. Friedenwald, Baltimore.
XXIV. Neuroblastic Tumors of the Sympathetic Nervous System. M. Bielschowsky, Berlin, Germany.
XXV. Neural Proliferations in the Vermiform Appendix. Pierre Masson, Montreal, Canada.
XXVI. Tumors of the Hypophysis Cerebri. Percival Bailey, Chicago.
XXVII. Malformation in the Central Nervous System. J. H. Globus, New York.
XXVIII. Hydrocephalus and the Atrophy of Cerebral Compression. W. Penfield and A. R. Elvidge, Montreal, Canada.
XXIX. Inflammatory Cells in the Central Nervous System. J. G. Greenfield, London, England.
XXX. Cells in the Cerebrospinal Fluid. W. Boyd, Winnipeg, Canada.

It is impossible to overpraise these volumes, for the editor and the publishers have done a great service in gathering together the information contained therein; the reader has made available to him in three volumes information that he otherwise could not obtain excepting with the most exhaustive research. Moreover, each author has summarized his opinion in much shorter space than otherwise could be obtained in original publications. No neurologist, neuropathologist, neuroanatomist or neurosurgeon can do without these volumes. A word of praise should be given the publisher, who has done his work exceedingly well. The illustrations, of which there are 886, 15 in color, are beautifully done.

Les malades dits imaginaires. By M. Nathan. Price, 14 francs. Pp. 134. Paris: Gaston Doin, 1931.

In choosing the subject of this volume the author struck a valuable note. From the days of Molière, the label "imaginary malady" has been commonly used in a derogatory sense. It is primarily for the sake of these patients and moreover for the good name of the medical profession that any attempt on the part of the physician to demand a more positive statement regarding patients with so-called imaginary illnesses should be welcomed.

Nathan treats his theme under the following five headings: (1) patients with so-called imaginary illnesses because of diagnostic error; (2) those with cenesthopathia; (3) those with obsession and phobias; (4) those with pithiatism, (5) and those with hypochondria. The discussion of each of these groups is the more intelligible, thanks to the fortunate mode of presentation, that is, conciseness and clearness, inherent to the French language, and the relative abundance of clinical material borrowed from the literature and mainly from the author's own observation.

The first group comprises patients in whom the numerous complaints are associated with somatic findings, such as vesicular atony, alkalosis, signs of imbalance of the vegetative system and suggestions of endocrine disorders. Most noteworthy are the affective disorders of the melancholic or manic type. From the standpoint of pathogenesis Nathan reckons with the more or less pronounced visceral involvement, plus the "secret garden" of mental factors and, specifically, emotions. Emotions by virtue of frequent repetition would determine Dupré's "emotive anaphylaxis."

In the chapter on "cenesthopathias" Nathan tries to prove that patients belonging to this none too well defined group are actual sufferers and their complaints perfectly justified. Dupré emphasizes the affective condition as an additional element and with Camus gives the following definition of cenesthopathia. "Disorders of the primitive elements of the organic sensibility, the painful vibrations emanating from one or another cenesthesic area." Patients with cenesthopathia often describe their complaints in picturesque terms, such as changes in size of certain organs, their excessive mobility or fixity, the shortening of the means of attachment of various parts of the body, resulting in traction of the nerves, and the like. Recognizing that in many cases separation from hypochondriasis is impossible, Nathan points to the present-day tedency to ascribe cenesthopathic troubles to "an actual lesion, no matter how apparently insignificant the latter may be."

In the discussion of the troubles of those afflicted with phobias, obsessions, pithiatric and hypochondriacal disorders, the author refers to clinical observations in which by various methods of approach, including the psychoanalytic one, one has succeeded in putting one's hand on an actual disorder. Nathan contends that one is compelled to discard the label "imaginary" as inadequate, unless one chooses to commit the grave error of mistaking affective disorders and abnormal psychic reactions in general for imaginary troubles.

The reviewer believes that the data offered in this book present a general medical interest and particularly answer a need of the nonpsychiatrically trained physician. This small volume treats complicated problems in a clear form and in plain, intelligible language.

Prohibiting Minds and the Present Social and Economic Crisis. By Stewart Paton. Price, $2. Pp. 198. New York: Paul B. Hoeber, Inc., 1932.

In this volume, the author—a pioneer of American psychiatry and one of its most venerated personalities—speaks his mind about the ills of the present time. As one of the prime causes of confusion, Dr. Paton discerns an attitude of mind. It is an attitude of "feelers," not of "thinkers." The author calls it the "prohibiting attitude." He sees prohibitionism at work in different parts of the world, in Prussia, in Russia and in the United States. There are today, he explains, many people who fail to accept the lessons that can be drawn from history. These people resemble neurotic persons who make attempts to conceal their fear of the past.

The prohibiting minds believe that the control of human activities is merely a matter of authority. But to control human behavior rationally, one must understand much better the emotional trends of the individual, which must be intelligently directed, and cannot just be forbidden. Only a "do" attitude on the part of the constructive thinkers (and not a "don't" attitude on the part of the prohibitionists) can remedy the emotional difficulties which, according to the author, lie at the root of the social ills. Dr. Paton's book is an exposition in modern terms of the statement of St. Augustine, which he quotes: "For the effort to make men abandon even a great evil and cleave to a great good produces more trouble than benefit, if they merely act under compulsion and not from conviction."

What is so commendable in Dr. Paton's book is that his criticism of prohibitionism is not only severe but also constructive. He is not fanatical, as are some antiprohibitionists, who have nothing to offer except that they would like to prohibit prohibition. Dr. Paton has a scientific as well as a charitable attitude. He thinks that old social systems are being discarded at present because they do not fit the emotional needs of present-day man. In short, here is a scientist who wishes to teach all those who have something to do with the control of human behavior that not only should an experiment be "noble," it should also be scientific.

The book is clearly written and contains a number of gems of expression; e. g., "We devote so much time to applying the brakes that we do not learn how to drive."

Dos reflejos neurovegetativos. By Fernando Gorriti. Two volumes. Pp. 1350. Buenos Aires: "Semana médica," 1931.

The relation of the oculocardiac and the solar reflex, brought to the attention of the psychiatrist through Laignel-Lavastine and later largely by Santenoise of the Paris School, receives in these two closely printed volumes a detailed account of 2,102 cases of psychoses, 408 of them with pharmacodynamic tests. The cases are reported under the headings of a nosological classification. In the great majority of the cases there was no antagonism of the two reflexes; the two were, in 83 per cent, of the same neurovegetative tone in the same patients, more frequently vagotonic (79 per cent), and less frequently sympathicotonic (42 per cent of the total number). Of the remaining 16.5 per cent, 9.8 per cent showed the antagonism as vagotonic in the oculocardiac reaction and sympathicotonic in the solar reflex, and in 6.7 per cent the reverse. The relations are not specific for any disease type, as the author had shown fifteen years ago. Epinephrine, atropine and pilocarpine were used for counter tests. The sympathomimetic agents do not always act on the two reflexes in the same way. The solar reflex, like the oculocardiac reflex, behaves sometimes in a vagotonic and sometimes in a sympatheticotonic sense. The oculocardiac reflex is open to fewer causes of error and has a more definite and outspoken neurovegetative tonus; the solar reflex responds with less irregularity to sympathomimetic substances.

This study makes one wish for collateral reactions of relatively clearer significance than the nosological diagnoses. The visceral reactions and the skin resistance share with most psychobiologic reactions the difficulty of one's knowing what is part response, or physiologic in the narrower sense of the word, and what is actually of an emotional or other definable psychobiologic response. Until a clear demonstration can be made, the preoccupation with the pertinent methods will belong to amplifying ritual rather than to leading or even decisively discriminating resources of psychiatry.

Ueber Heilungsmechanismen in der Schizophrenie. By Max Müller. Price, 14 marks. Pp. 143. Berlin: S. Karger, 1930.

Curative tendencies are defined as all the processes in a schizophrenic illness that tend to cause a "social-biologic" improvement. The author believes in an organic basis for schizophrenia, but attempts his analysis on a dynamic-genetic approach. He first discusses the importance of the affective relations to the environment. The essential step is that of curing by transference the regression to the narcisistic stage. His case material is not convincing that such a heterosexual or homosexual fixation to the physician or to persons in the environment is essential or desirable. The discussion of occupational therapy, in which the author has a wide experience, is of interest. He points out strivings and interests of the patient that can be utilized in breaking through the autistic isolation. He also urges that the "reactive symptoms" in schizophrenia, e. g., those caused by treatment in a hospital, can be prevented and removed through a more individualized routine. The second chapter discusses the patient's attitude to delusions and the tendencies that lead to an adjustment. Case histories illustrate the formal adjustment by rationalization and the adjustment of the underlying factors by compromise. The latter may lead to an adjustment of the delusions to reality without or with obvious social biologic improvement. Some patients find in the reality reasons that argue for a wish-fulfilment, without a correction of the delusions. More satisfactory is the intellectual correction of the delusions. In these cases the delusions may later still be recognized in autistic planning. The mechanisms of repression and their curative possibilities form the third chapter.

This monograph is stimulating and presents the various approaches to treatment, but does not pay much attention to psychiatric work done outside of German-speaking countries. One misses a constructive synthesis of the material presented. The author takes the psychosis too much as an independent unit and does not pay sufficient attention to a study of the personality and the situations involved.

Lehrbuch der experimentellen Psychologie. By Joseph Fröbes. Volumes I and II. Price, $12.50. Pp. 1305. St. Louis: B. Herder Book Company, 1929.

Since the last edition of Wundt's treatise there has been no attempt to cover the field of experimental psychology and its ramifications into the higher mental processes in as comprehensive and thorough a manner as is done in this textbook. It is not merely a thorough review of the leading studies on methods and results of the pertinent researches, but is obviously written with much understanding of the needs of serious practical workers in the field of the higher mental processes. A pupil of G. E. Müller and professor of philosophy in a theological school, the author presents what science has yielded and what the relations are to the domain of art, morality and religion. With obvious orthodoxy in the doctrinal part of the work, the author gives an excellent objective statement not only of the experimental work, but also of the psychologic data in the psychoses and in psychopathology and psychotherapy, with compact reviews of the concepts and critical statements of the various investigators.

The first volume deals with the sensations and elementary feelings, perceptions (including time and movement), psychophysical problems and associations. The second volume begins with the disorders of association and cerebral localization, the complex processes of attention, the age, memory, intelligence, fancy and language; the complex feelings and emotions, esthetics, mimic, the volitional life, the goals of life, the total personality and mental development; social psychology; the anomalies of consciousness, sleep and dreams, and the mental disorders. The presentation is clear. Concise consideration of the literature makes the book valuable for reference as well.

In another work, "Psychologia speculativa," published in 1927, the author deals with the philosophic aspects of psychology.

Foundations of Abnormal Psychology. By Fred A. Moss, Ph.D., M.D., and Thelma Hunt, Ph.D. Price, $4.50. Pp. 548. New York: Prentice-Hall, Inc., 1932.

Most books on this subject emphasize the purely functional elements with special emphasis on the most recent or freudian theories. As a contrast this book deals mostly with the organic aspects, and as such it is welcome, for, after all, while there has been considerable progress in knowledge of the psychobiology of mental disorders, the organic elements still remain the groundwork.

The book is divided into two parts, the first dealing with general considerations of mental disorders, and the second with specific diseases. In the first part there is an interesting chapter on who is normal, and the author takes up the question of what are normal heredity, environment and past life. Studies of normality have been attracting increasing attention in the last few years, for they show that many of the factors that are considered pathologic are really variations of the normal. This has been well shown in child studies. There is no reason why similar research in the adult normal, particularly in regard to mental functions, should not be of equal value. It can readily be pointed out that the diagnosis of the abnormal from the normal is often of the utmost difficulty.

Altogether this is a good book for the student and social worker, and it is likely to be of considerable help to the layman, for it is written in easy language and the text is not at all controversial.

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